The Paperless Classroom: Tablet PCs in University Teaching

by

Charles Jordan Gilliland

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Author ....
Department of Electrical Engineering and Computer Science
January 30, 2004

Certified by ....
Professor Gerald Schneider
Thesis Supervisor

Certified by ....
Dr. Rutledge Ellis-Behnke
Thesis Supervisor

Accepted by ....
Arthur C. Smith
Chairman, Department Committee on Graduate Theses

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Chapter 1

Introduction

1.1 Introduction

The fundamental purpose of this thesis is to provide the data and conclusions which resulted from a project started at MIT in Spring of 2002 (but conceived much earlier) called *The Paperless Classroom.* The basic mission of the Paperless Classroom was to eliminate use of paper in two Neuroscience courses while maintaining or increasing the level of performance of the students. The ultimate mission is to determine why the initial test did or did not maintain or improve performance, and if it did, to extend the Paperless Classroom to other classes, and perhaps even to make it university-wide.

The benefits of eliminating paper are numerous—decreased photocopying costs, decreased time required for instructors to produce photocopies, a positive environmental impact, reduction in students' and instructors' space need to store paper, and the list goes on. The actual means of eliminating paper were never really a question, the assumption from the start was that if paper were to be eliminated, then something paper-like would have to take its place. With or without paper, students will need to take notes, read documents, take quizzes and exams, and graphically develop and convey thoughts, so something that serves all of these functions is needed if paper is to be removed from the classroom. Fortunately, recent major advances in one particular area of technology helped provide a cogent solution.

1.2 Enter the Tablet PC

Paper-replacement technologies have existed for some time, a particular technology called the *Tablet PC* dating at least as far back as GRiD Computer Systems' GRiD-Pad 1900[1]. At the most fundamental level, a Tablet PC is a computer, generally a relatively portable one, that allows the user to write directly on its screen using a pen (or *stylus*). Since things written on the screen can be saved for later use, the Tablet PC was a clear candidate for paper replacement.

What made Tablet PCs an especially viable solution was the fact that Microsoft mounted a major effort to push the Tablet PC, going so far as to create a special version of its Windows operating system called *Microsoft Windows XP Tablet PC Edition* which I will refer to simply as *Tablet XP*. In cooperation with this effort, various computer manufacturers created Tablet PC hardware designed to run Tablet XP and these efforts constituted a quantum leap in Tablet PC hardware and software. The result was a new breed of computers, officially released on November 7, 2002 along with the new operating system, which were truly meant to be used as an electronic replacement for paper.

However, other paper-replacement technologies do exist, such as digital pens that remember what they've written, or perhaps the largest contender, the PDA or *Pocket PC*[2], but we spent little time determining that the Tablet PC was the most appropriate device to use. No formalism was used in making this decision, rather, we appealed to common sense, though others[3] would seem to differ in their notion of what constitutes common sense and receive substantial press for distributing PDAs to an entire class of middle school students, expecting them to perform all the functions of paper on a device with a screen at most 4" along the diagonal[4], and with keyboard buttons less than 5mm in width. Anyone who has watched *Star Trek* knows that, in the future, screens are much bigger than that. In the case of Tablet PCs, all but a rare

[1]See http://www.griduk.com/History.htm

[2]Not to be confused with the *Handheld PC* which is larger than a Pocket PC but smaller than a Tablet PC, with screen diagonals ranging from 6" to just over 8"

[3]E.g. previous paperless classrooms like the one at Eminence Middle School in Kentucky, see http://www.paperlessclassroom.org/

[4]Actually, 3.8" was the largest I could find, with most being 3.5"

few have screens at least 10.4" in diagonal. Ultimately, it is our belief that in order for a device to be as useful as 8.5"x11" paper, it must have a writing surface that is at least of the same order of magnitude in size as paper, so this rules out PDAs altogether.

1.3 The Neuroscience Courses

To further understand our motivations for establishing the Paperless Classroom, it is helpful to have some background on the pilot subjects. The first subject, 9.01[5], is the main introductory Neuroscience course for undergraduates in the Department of Brain and Cognitive Sciences at MIT and is taught each Fall by Professor Gerald Schneider, Principal Investigator for the Paperless Classroom project. Course number 9.14, the follow-up course to 9.01, is taught each Spring, also by Professor Schneider, and is quite similar to 9.01 in difficulty, content, and structure, but focuses more on the development of the brain. In each of these courses, there are several thousand pages of photocopied handouts[6], and 99.9% of them are in black and white despite the fact that many of the diagrams in these pages were originally done in color. These handouts fall into several categories—there are printed versions of PowerPoint slides distributed at the beginning of lecture each day so students can annotate the slides as the Professor refers to them in class. There are readings to be done outside of class which consist of journal articles or particular chapters from Neuroscience texts. Finally, there are one or two required textbooks and one or two optional textbooks. The total amount of paper is astounding and poses several problems for students taking 9.01 or 9.14. One of the goals of the Paperless Classroom was to alleviate these difficulties, hopefully improving students' performance.

[5] MIT refers to its courses by number more frequently than by name.

[6] I took both courses myself and they each occupied about two feet of bookshelf space.

1.4 The Structure of this Document

The remainder of this thesis will consider the following topics in greater depth: our motivations for eliminating paper (Chapter 2), briefly review prior studies on technology in teaching and previous projects similar to ours (Chapter 3), compare the Tablet PC to laptops, provide evidence showing why laptops are insufficient for our purposes (Chapter 4), discuss the major implementation issues which we were faced with when creating the Paperless Classroom and describe the implementation choices we decided on (Chapter 5), review Tablet PC hardware and why we chose the machines we did (Chapter 6), describe the distribution and subsequent use of tablets in a Neuroscience course over two semesters and our informal, qualitative observations during those semesters (Chapter 7), describe the formal measurement techniques we used to determine the effect the tablets had on student performance and provide the data that resulted from those measurements as well as an analysis and interpretation of said data (Chapter 8), and finally provide conclusions as well as suggestions for future work (Chapter 9).

Chapter 2

Motivation for Creating a Paperless Classroom

There are five main reasons to replace paper with tablets in the classroom. First is the resulting increased potential for organization by all parties concerned, and second, the related but somewhat different notion that when in electronic form, information is easier to access not only because of increased organization, but in this case because it can all reside in a single physical location. Thirdly, there is the fact that this single repository of information is portable, which increases ease of access to information. Fourth is the availability of color on Tablet PCs that, while not theoretically unavailable on paper, is practically unavailable because of the extremely high costs of color printing. Fifth, while it may at first seem doubtful, there is the potential to reduce total institutional cost by switching from paper to tablets.

2.1 Organization

While people may differ in their skills at organizing paper and computer files, there can be little doubt that computer files are ultimately easier to organize. Ease of organization in this case can be defined as either the total time required to achieve a given level of organization or the level of organization achievable given a fixed amount of time. Organization itself is a somewhat amorphous concept, but can be thought of either in terms of some absolute, measurable quantity that is static across individuals, or something which varies from person to person. I will take a pragmatic approach and define organization as the amount of time required for a given individual to locate each object that has been organized. Thus the organizational process has two components: the storage of an object and the retrieval of that object. Presumably, it is more desirable to reduce the retrieval time than it is to reduce the storage time since a person generally stores once and retrieves often.

Organizational systems which minimize retrieval time tend to be those that have features we would intuitively expect from an organized system. For example, there is often some sort of hierarchy that groups a large number of objects into a tree structure, and this happens to parallel the hierarchical structure of computer file systems. A directory can contain files (terminal nodes in the hierarchy) or other directories (non-terminal nodes in the hierarchy). The degree to which directories can be nested is limited only by the specific filesystem being used. While it is in theory possible to organize actual paper in a hierarchical fashion, any inspection of reality reveals that the organization of paper tends to result in a much flatter tree, i.e. one with very little hierarchy to speak of. Consider the various means of storing paper—a bookshelf is almost certainly a linear ordering of objects with little hierarchy to speak of. Treating different shelves within a bookshelf or different bookshelves as different directories adds one level to the hierarchy, but this pales in comparison to what is easily accomplished with a computerized filesystem. A file cabinet is another paper storage system—in this case, some hierarchy is possible by placing paper within folders, and perhaps even nesting folders within folders, but the physical properties of paper limit the extent to which such nesting is possible. Thus, to whatever extent hierarchy is useful in reducing retrieval time, computer files are easier to organize, using the definition of organization given above.

Of course, reduced retrieval time is not the only benefit of hierarchical organization. Objects of similar origin, content, or function also tend to be grouped together so that they are proximate in the hierarchy. In computer terms, files or folders that are related tend to reside in the same folder. Thus, when accessing a given object, it is also possible to see an additional set of objects that may be relevant as well.

Yet another benefit of increased organization is the decreased risk of misplacing or losing an object. Though I will give no formal proof that it is harder to lose a computer file than a piece of paper, I will state in a later section that students cited the decreased chance of losing their notes as one of the benefits tablets afforded them.

This increased potential for organization benefits not only the student, but the TAs and professor as well because, in the Paperless Classroom, paper is eliminated across the board.

2.2 Simplicity of Access

Another benefit of using a computer to store information instead of paper lies in the fact that modern hard drives are large enough to accommodate entire libraries of information. For the student, this means that what would normally take up an entire bookshelf can now reside in a single small machine. While paper has the potential to be spread about to occupy multiple physical locations (e.g. home and office), this problem is reduced to the lesser problem of file synchronization in the electronic realm. Thus, even if a person has data in multiple computerized locations (e.g. desktop and tablet), the challenge generally lies in maintaining fresh copies of data in all locations, but assuming synchronization is maintained, absolutely nothing prevents the user from having access to all of their information at once via a single machine. The result is that accessing information is greatly simplified because there isn't really a question of where the information is physically—it's in the computer[1]. Given that, all that remains is to locate the information within the computer, which is easier because of the organizational benefits described above.

[1]See *Zoolander*

2.3 Ubiquity of Access

As a corollary to the notion of simplicity of access, we have the notion of ubiquity of access—since Tablet PCs are extremely portable[2], it is possible to take all of one's information anywhere one wishes, so not only can you have access to all of your information in one place, but you can have access to it from *any* place. For the student this means that few things, short of (or perhaps including) eating and sleeping, can get in the way of studying. There are also secondary benefits to having access to information everywhere. For example, students might be more motivated to study if they can vary their study location, or they might have an easier time studying with a friend or study group because of their ability to take all of their work with them no matter where they go.

2.4 Color

One benefit of viewing information on a computer versus the printed page lies in the computer's ability to display color. While color can be produced on paper, the cost is prohibitively high—the cost to us when we photocopy color pages for our Neuroscience courses is roughly one dollar per page. This may sound reasonable, but given the total number of pages of handouts that use color in a meaningful way, it would be impossible to copy any significant fraction of them in color. But on a computer, it costs the same to display something in color as it does to display it in black and white.

Understanding why color is so helpful may be difficult without some examples, so I have attached several color handouts from the Neuroscience courses as well as their black-and-white counterparts. (See figures B-1 through B-4.) The usefulness of color lies in the fact that it encodes additional information while still occupying the same amount of space on the page. It is also easy to quickly group objects on the page by color, which is easier than grouping objects by shape, for example (as shown in B-1), so finding areas of commonality in a colored diagram is much easier when color

[2]Usually 3 lbs, sometimes as much as 5 lbs

information is intact. While I will not give a formal description of the benefits of having color, the examples given are not atypical and should suggest the usefulness of color.

2.5 Cost

My initial belief when beginning this project was that it would increase the cost of education because any savings made by reducing paper consumption would be easily outweighed by buying enough tablets for a classful of students at almost $2000 a piece. In a sense, this is correct, assuming that the Paperless Classroom were to remain in its present experimental form. However, the ultimate goal of the Paperless Classroom can only be to make a Paperless University. Granted, it is impractical to eliminate all paper at all levels of the University, but over time I have become more and more convinced that conversion of the academic core (i.e. the students and instructors as opposed to the administrative personnel) of the University into a predominantly paperless environment is possible and beneficial.

The benefit in pursuing a widespread elimination of paper lies in the fact that it allows you to make major changes in a number of areas that literally reshape the campus while conferring financial savings. For example, a small implementation of the paperless campus is not nearly as efficient as an extensive one because it requires most of the paper infrastructure to be retained. In a large scale implementation, to whatever extent paper is eliminated, this paper infrastructure can be eliminated which means financial savings due to

1. Not having to purchase additional printers and photocopiers
2. Not having to pay for the maintenance of printers and photocopiers or associated maintenance personnel
3. Not having to pay for the paper itself
4. Making better use of university space currently dedicated to public printers

2.5.1 Public Computing Spaces

All of this begins to hint at a related topic, one which I cannot spend too much time discussing but should briefly mention—the fact that since eliminating paper entails each student having their own tablet, there is a dramatic reduction in the need for a public computing infrastructure on campus. At MIT, this public computing system is called *Athena* and after 20 years in operation, usage has started to decline due to the increased numbers of students with personal computers, laptops specifically. Plans are already in place at MIT to pare down the existing Athena system, and a Paperless University could only accelerate this process. Complete elimination of the public computing system is probably not desirable or necessary, but unused machines are unneeded machines and enormous savings could be made by reducing the expenditure on public computing hardware, software, maintenance personnel, and associated space. In the case of MIT, it turns out that a number of large public computing spaces will be at least partially converted for other uses. In fact, it is likely that many of these spaces will remain public computing spaces, but will contain less (or at least different) equipment, and will instead adapt to the needs of users of mobile computers such as tablets and laptops. For example, this next-generation computing space would certainly contain relatively few public computers but might contain more projection systems, allowing users to connect their tablet or laptop to a larger display for purposes of discussion or presentation in small groups.

In any case, when considering the cost-viability of the Paperless Classroom it is crucial to consider the cost-viability of the Paperless University in which the expense of over a thousand dollars per student is not only made up elsewhere but also results in a host of benefits which increase the effectiveness of each dollar spent.

Chapter 3

Prior Work

While there is very little prior work regarding the educational use of Tablet PCs, there are studies describing somewhat similar uses of educational technology. A few studies describe the technology-mediated replacement of paper with precursor tablet technologies or note-taking systems that require only the use of a mouse and keyboard, but a greater number of studies describe the technology-mediated *elimination* of paper, by use of laptops. This section will consider prior studies of both of these conditions, as well as studies regarding wireless technology, educational use of technology in general, and conclude with a review of what is perhaps the most important area of literature—that concerning students' traditional note-taking methods and their impact on student performance and future recall of information.

3.1 Tablet PCs

3.1.1 Ideological Variation

Ideas regarding the potential for devices such as the Tablet PC to reshape university education are by no means new. Langenberg and Spicer [26] recently described a futuristic view of university education which considers technologies such as the Tablet PC. They provide the following account of a typical student experience in this *Modern Campus*:

> "Members of her entering class were the first to be required to purchase wireless digital assistants. This book-sized computing device is set up to look first at her personal university portal (PUP). From anywhere on campus she can communicate with classmates and faculty, take a preliminary look at the notes and materials that the professor in her next class will be discussing, and access library materials. In fact, many of her textbooks have been downloaded into the digital assistant as well so that she has all of her materials wherever she is." [26]

The largest innovations in this environment described by Langenberg and Spicer include a number of ideas that are realized in the Paperless Classroom, most importantly the notions of access to course materials as well as library content wherever the student is and whenever the student wants. Some statements are strikingly reminiscent of actual conditions at MIT:

> "His course materials are always available on-line to members of each of his classes. At first, creating these materials in electronic format was time consuming, but the university offered support and training to simplify the job. Easy-to-use course development and course management tools were licensed for all faculty members. Training in how to use these tools, and more important, in how to create a learning environment in an electronic medium, was provided." [26]

However, a few comments indicate where our philosophies diverge:

> "[A student's] classroom discussions are always lively, and because each student has a digital assistant, there is no need to focus on taking notes [...]. Additionally, the observations her professors write on blackboards can easily be downloaded into each student's digital assistant after class, thanks to the technology built into her university's smart classrooms [...]. [The student] has a more traditional computer in her dorm room that is connected to this network and that synchronizes information with her digital assistant." [26]

Because these descriptions fully describe the Paperless Classroom in some regards and disagree in other areas, they are representative of the current assortment of ideas regarding the proper direction for technology in education. Few doubt the benefits of increased ease of access to course content and the benefits of consolidating a student's entire educational universe (or at least the non-human components of it) into a portable device, but contention still exists regarding the exact means of accomplishing these goals. The statements above provide an interesting example of partial awareness regarding the potential of technology in education—while a number of key benefits of projects such as the Paperless Classroom were cited, misconceptions regarding what these technologies will and will not replace are still pervasive.

The only effective means of combating such confusion is to carefully consider the actual impact, as suggested by supporting literature, of each proposed change. Langenberg and Spicer comment *[T]here is no need to focus on taking notes.*, for example, yet the fact that a piece of technology makes it possible to stop taking notes does not necessarily mean that note-taking should stop, especially given what is known about the function of note-taking: while students can perform well without notes, the highest performance tends to come from those who review notes they took themselves (to be discussed in detail in section 3.6).

The Langenberg and Spicer comment *[The student] has a more traditional computer in her dorm room that is connected to this network and that synchronizes information with her digital assistant.* also imposes unnecessary complexity in computer users' lives—the notion that file synchronization[1] will be necessary in the future is not necessarily wrong, but certainly is questionable since a device such as a Tablet PC can be used anywhere, including at home. The model for the future is emerging as one in which a person carries his data everywhere (and perhaps an interface as well), but in which interfaces are pervasive. Interfaces such as public screens and projection systems may remain relatively large, and therefore anchored, for some time,

[1]File synchronization is the process of updating any changes made to files which exist simultaneously in multiple locations. For example, a tablet can be synchronized with a desktop computer so the desktop has current versions of all files that were modified on the tablet since the last synchronization.

but one's personal data can occupy an extremely small amount of space, and thus can be taken everywhere, precluding the need to store said data in multiple locations, backup notwithstanding.

3.1.2 Tablet-related Studies

The variety of ideas about how to implement the Paperless Classroom gives rise to studies that describe similar, but far from identical, means of replacing paper with an alternative note-taking device. Ward and Tatsukawa [54] note that while paper has been replaced by technology in a number of domains, replacement of paper for purposes of note-taking lags behind, because of the unique requirements of note-taking, and the resultant lack of software which properly supports it. In response to this lag, Ward and Tatsukawa designed a software system that allows note-taking, citing benefits of searchability, editability, ease of sharing, and legibility. (They also mention, in agreement with my prior statement, that the notion that note-taking should be eliminated by technology is unfounded.)

A list of nine properties of notes is given[54]— 1) notes are generally used by the person who took them and therefore need only facilitate retrieval of memories for that specific person, 2) notes are reviewed during the term and need not be permanent and are therefore messier than formatted documents, 3) notes consist of short text chunks, 4) the spatial layout of notes is important and they can be two dimensional in their layout as well as linear, 5) text and graphics (including arrows, boxes, etc) are commingled in notes, 6) notes taken by students can be lengthy because students want to capture as much material as possible, 7) notes are written under time pressure, 8) note-taking is done at a classroom desk with a limited amount of space, and 9) notes are revised infrequently (although they note that digital content is more easily revised with frequency). These descriptions are, more or less, agreeable and serve to confirm much of what will be said in chapter 4 regarding the need for tablets instead of laptops because they make it clear that notes are far more than a simple string of text which is what taking notes with a laptop generally provides.

Ward and Tatsukawa [54] also note differences between different types of note-takers, stating that office workers, for example, differ from students in that they are more selective in what they write down and their needs are therefore met even with the small screen of a PDA. They also note that office workers are more willing to tolerate less efficient input methods (such as graffiti) because of their selectivity in note-taking and the relative lack of time pressure during note-taking. This difference reinforces the notion, to be elaborated upon later, that the Tablet PC, not the laptop or PDA, is the proper device for use in the Paperless Classroom.

Ward and Tatsukawa [54] also state that since the keyboard is faster for production of text, the insertion of text boxes should be supported in a note-taking system and that the pen and keyboard should be supported side by side—pen for graphics, keyboard for text. This is basically true, but it fails to mention that the pen is also useful for creating short-to-medium length text strings at arbitrary locations and with arbitrary orientation on the page. In any event, the Tablet PC note-taking software does allow the insertion of text boxes as well as interchangeable use of the stylus and keyboard. In fact, an example of a student using their tablet in just this manner is given in figure B-49.

Based upon these notions of what was required for a note-taking system, Ward and Tatsukawa constructed note-taking software and provided it to a set of test subjects. The sample size was rather small, but the subjects generally found taking notes electronically to be a suitable replacement for using pen-and-paper. The subjects were interviewed and cited a number of advantages of using the note-taking software, namely that their notes were more legible, could be taken more quickly, were easier to edit later, searchable, and easily backed up. Some of these benefits, however, such as the increase in note-taking speed, may have been due to the greater emphasis that was placed on use of the keyboard for taking down text. Disadvantages cited included difficulty drawing complicated figures, low battery life of the tablets being used, and difficulty keeping up while note-taking. Since they were using older tablets than those currently available, it can be expected that some of their problems would be alleviated by use of modern hardware.[2]

[2]The tablets being used employed the older, passive, digitizer technology which is explained in

Another example of technology used for note-taking is given by Bargeron, et al[3]. Their study describes a system for annotating video (of lectures, for example) which does not make use of tablets at all, and simply provides an interface for linking text typed with the keyboard to video segments. It is, however, an example of a system specifically designed to replace note-taking, and thus could be considered an alternative to our tablet-based note-taking strategy. They compare test subjects' use of paper to take notes with their use of their new annotation system, noting that paper-based notes exhibited little contextualization—determining what part of the video a given textual item referred to was quite difficult. Although it was not the intention of their study, this points out an advantage of annotating lecture slides (as we have students do in the Paperless Classroom) rather than taking notes on blank paper—lecture slides automatically provide context for any text present. This study concluded that users preferred the computer-based annotation system over the use of paper, for reasons of organization, readability, and contextualization. While the note-taking system proposed for the Paperless Classroom does not automatically position students' notes for them, it is assumed that students are comfortable taking notes on whichever lecture slide is currently under consideration. Furthermore, the mere fact that notes taken on tablets are in digital form results in organizational benefits, as described in section 2.1. While the Tablet PC mimics paper, and thus does not increase readability per se, it does make correction and erasure of notes much easier and it can be expected that readability will increase as a result. Finally, the issue of contextualization has already been addressed. While this study does not support, or pertain to the use of tablets, it does indicate that note-takers are willing to use technology to take notes in place of paper. One clear disadvantage of Ward and Tatsugawa's system is that it precludes the use of any diagrams or special notation not easily entered with a keyboard.

Vertical markets, such as hospitals and law enforcement, were early adopters of tablet technology, in part because the tablets' served their need for on-the-go access to data such as patient or criminal records. Buchauer et al [7] describe a small study

section 4.2.1.

of the use of early tablets in health care. Salient findings include the fact that they found these early tablets (then called *pen computers*) too large and heavy for mobile use. This stresses the need for portability which will be discussed in chapter 4. They also note that the tablet should have a keyboard to allow entry of larger blocks of text. This will be of relevance in chapter 6 when specific tablet models are discussed.

3.1.3 Informal Survey of Tablet Projects

Because the Tablet PC is a relatively new technology, at least in its present form, the majority of the information concerning its usage comes from informal sources, such as case studies which, at best, provide summary statistics for surveys regarding tablets and tablet usage. While these sources cannot bring anything to bear on the use of tablets in education in a formal sense, briefly reviewing the list of educational case studies and projects is helpful simply to get an idea as to how widespread the use of tablets is in other academic institutions. Since this an informal survey and since these are not published facts, the information was exclusively obtained from Internet searches, and as such, the findings may not be completely accurate. Visiting the web site for each institution mentioned is the easiest way to determine the current progress of their respective Tablet PC projects.

An as-of-yet unpublished study[3] which analyzed expected Tablet PC market performance was conducted at Bentley College. The study cited (presumably via the distribution of surveys to college students) that 38 percent of all students were likely to use tablet PCs in the classroom , that both slates and convertibles were accepted form factors (to be described in chapter 6), that 54 percent of students were willing to pay $2,000 or more for a Tablet PC, and that large-scale conversion from laptops to tablets will take place in the Fall of 2004. While these findings are not from an official, citable source, they merit consideration particularly because they are the only such data available at this time. The study also revealed some concerns, namely that of dependability (hinge reliability and loss of the stylus), Tablet PCs' not suiting stu-

[3]See the *University Business* magazine article at http://www.universitybusiness.com/page.cfm?id=300 or the Bentley University site at http://www.bentley.edu/research/

dent lifestyles outside of the classroom (apparently because of their lack of a built-in DVD player), the preference of styli by older users, the keyboard by younger users, and the need for word-of-mouth, on-campus placement programs to spread the use of tablets on campuses. This study, if accurate, reveals a number of ways in which students in our Paperless Classroom differed—over half of students volunteered for tablets (versus 38%), only one stylus was lost over two semesters' time, students seldom complained about the lack of a built-in DVD player (although it was mentioned by a few students), and the students were universally comfortable using the stylus, although not necessarily at the exclusion of the keyboard.

While Bentley simply performed an analysis of Tablet PC market penetration, a number of educational institutions have actually used tablets in their classrooms, unfortunately providing relatively little formal description of these usages. For example, Bishop Hartley High School in Columbus, Ohio provided a Tablet PC to each of its 142 seniors, citing benefits such as increased organization, reduced physical burden, anytime, anywhere access to materials, and reduction in paper-related costs. John Paul College in Queensland trialed Tablet PCs to determine their educational value to them, but no formal feedback was made available. Louisiana State University has an exploratory tablet initiative, although it would not appear to be as pervasive as one of their news pages indicates: *The Student Senate is considering a resolution to enact a Mobile Computing Initiative, which will require all incoming freshmen to have laptop computers.* MIT has also been involved in Tablet PC-based projects in the past—MIT hosted the 2002 International Design Contest (IDC), in which teams of students used Tablet PCs (thanks to a Microsoft *iCampus* grant) to collaboratively design robots. Feedback was generally positive although no formal study was performed.

A Microsoft Case Study of schools in Greenwich and Kent, England provided students in two schools with the opportunity to try Tablet PCs, citing uninteresting findings such as *The conversion of their handwriting into text gives immediate feedback on the quality of their writing.* There is currently a Tablet PC initiative at Notre Dame whose goals are to discover the potential use of tablets for faculty as well as the impact of tablets on learning, thought the degree of formalism they intend to use is not clear. A rather large project was being planned at Purdue for the Fall 2003 term, with "as many as 1,000 brand-new devices in some classes this Fall (2003). They haven't settled on a particular product just yet, but they know their upcoming strategy will hinge on the Tablet PC." How many of these devices were to be tablets is not clear but what is clear is that an *Information Technology at Purdue* grant resulted in their purchase of 42 tablets which were provided to students in their communication department for use in class. Students used the tablets to provide real-time feedback on speeches, for example.

Seton Hall University also used tablets in a pilot study, finding that most students who were provided with tablets switched from using their laptops to "almost always" using their tablets. Students cited problems with insufficient battery life, long setup time, and poor recognition of handwriting, and cited benefits including usefulness of tablets for annotation and note-taking, access to graphics, portability, and handwriting recognition (apparently there was disagreement on that point). Instructors cited benefits such as being able to write and face the class at the same time, resulting in heightened engagement with the class. Sharon Academy in Vermont tested tablets in various subjects, noting, for example, the benefits of Tablet PCs in art and drawing classes. A recent *University Business* magazine article [4] described how a Professor at Temple University connects his tablet to a projector, adding diagrams and flowcharts to his notes during class, and emailing them to students immediately afterwards. A project at University of Texas, Austin, provided some students in their architecture department with tablets, with students stating that the tablet was helpful for collaboration, mobility, and note-taking. They also noted that the tablets made it easier to access software packages, with the most useful software being Word, Journal, Excel, and Outlook Express, among others.

Common threads throughout these case studies include the notions that tablets result in increased organization and ease of note-taking and access to graphics, reduced physical burden (i.e. portability), increased mobility and the associated notion

[4] See http://www.universitybusiness.com/page.cfm?p=289

of anytime, anywhere access to course materials and software packages, reduced paper costs, greater ease of collaboration (e.g. team-based robot design), with drawbacks including low battery life (lower than that of paper, but not that of laptops, that is), long setup time, and problems with handwriting recognition (with some disagreement on this issue). While these were not formal studies, with many, in fact, based upon Microsoft case studies suggesting a possible bias, they nonetheless constitute the bulk of the information currently available regarding the use of Tablet PCs in education. The findings indicate a great potential for the use of Tablet PCs in the classroom, as well as a few challenges to be dealt with. Some of these findings are, in fact, supported by prior work as well as our own project. A formal discussion of these topics and others now follows.

3.2 Laptops

Since the use of laptops in education is relatively widespread (compared to the usage of Tablet PCs), studies regarding the use of laptops in educational contexts will prove to be a valuable means of placing the Paperless Classroom within the context of prior work. The Tablet PC does, in fact, share the majority of its features with laptops—they are both full-fledged computers,[5] they are both intended to be portable (whether they actually are portable is subjective and depends on the particular hardware), and they have comparable capabilities and specifications, with the obvious exception that the Tablet PC provides an additional input method, the stylus. (A detailed comparison of Tablet PCs and laptops is given in Chapter 4.) Thus, studies of the use of laptops in educational environments will, for the most part, be pertinent to discussion of the Paperless Classroom.

A study [45] of a project which saw the distribution of laptops to every full-time student and faculty member at the University of Minnesota, Crookston, revealed a number of relevant findings. The university handled the major issue of funding the

[5]I.e. they run the same operating systems as desktop computers, as opposed to smaller devices running special operating systems such as WindowsCE or PalmOS.

laptops by charging a technology access fee of $300 per quarter, although this fee covered items other than the laptops themselves (e.g. software, printers, etc). They describe their preparation for the widespread of laptops as follows:

> "Fifteen classrooms were remodeled to include Ethernet and electrical connections at each student's seat, a digital overhead camera and projection unit in the teaching station to connect the faculty notebook into the server system, and a printer. [...] A help desk, staffed from early morning to late night, serves as the distribution and service center, provides warranty service, checks out notebook computers for part-time students, and is a place for everyone to go for problem assistance." [45]

Major student uses of the laptops were said to include note-taking, communication with faculty, preparation of reports and presentations, accessing information, and solving problems. Significantly, students with laptops continued to take notes, with over 75 percent citing the act of note-taking or completion of other assignments during class as a major way in which they used their laptop. It would have been useful to know how their note-taking might have changed as a result of having the laptops, but such questions were not investigated in this study. Major findings include the statement by 87 percent of students that, after having the laptops, they could work more quickly and with greater accuracy, and 75 percent perceived an increase in the amount and quality of learning [45]. Surveys also indicated an increase in student-faculty interaction as a result of students' having laptops [45].

Among the final conclusions of this study were three points of particular interest—first, that students gain self-directed learning skills as a result of having anytime, anywhere access to materials, second, that the financing of university-wide laptop distribution is possible, especially when considering the benefits afforded, third, that

> "The "anytime, anywhere" features of portable computers necessitate dialup networks with a comprehensive technology support system, and multimedia capable classrooms with Ethernet and electrical connections to students' seats." [45]

This third statement is of particular interest because it points out one limitation of one-to-one computer access that is rapidly disappearing—the (expensive) need to rewire or remodel classrooms is greatly lessened when the devices being used have a long battery life and wireless networking capability. While the older model of laptops in education may have been to enhance existing and new classrooms with ethernet and power at every seat, the current model proposed by the Paperless Classroom requires neither of these things because long battery life and built-in wireless cards are assumed to exist in Tablet PCs. In any case, most of the findings of this study should apply to the Paperless Classroom as well, since Tablet PCs have all the capabilities of laptops, with the additional capability of stylus-based input.

A study regarding the distribution of laptops at Sacred Heart University [55] met with somewhat less success. Their original reasons for requiring all incoming first-year students to have laptops included their belief that it would alleviate the costs of computer labs on campus while achieving "computing excellence." To cover the costs of the laptops, an additional $359 fee was assessed each semester—it was also noted that "few responded negatively" to this added expense. It was also mentioned that students worked together in figuring out their new laptops' functionality, an indicator that introduction of new technologies in education is largely facilitated by the students themselves, as was borne out in our study as well (see section 8.2.5). However, it appears that things quickly went downhill once the laptops were introduced:

> "Once the semester was underway, students started having trouble. The hardware failed; the software got viruses. Because no consideration was given to issues of alternative keyboard and software design, as these might be needed by our learning and physically disabled population, several students were unable to use their laptops in class. The printers in the residence halls broke down. The computer staff was exhausted from working seven day weeks for months, and they snapped at students and were not able to take care of their problems. The company that provided the computers disappeared from campus; they were not a presence. [...] Students sent pornography over e-mail that faculty—to their surprise and

> dismay—received. Students downloaded virus-ridden material that led to "epidemics." They mistreated their computers—dropped them out of windows, placed them on stereos that altered internal electronics. They were rude to technical personnel when things went wrong (and the techies were rude right back). They were frustrated when they didn't know how to use the software and angry when they were thwarted in any way—they had, they reasoned, paid good money for these computers." [55]

In any event, this study seems to indicate that the prior level of computer experience of students and faculty need to be taken into account when determining the need for computer support services. In fact, two of the six reccommendations identified in this study pertain to faculty training:

> "Identify where faculty need support: training, testing software, development; schedule computer staff and faculty times to work together without pressure." [55]

> "Provide a faculty training center (a Culpepper Grant is going to help us) where faculty can go by themselves, without student interruption, to immerse themselves and receive training and help." [55]

It is clear that determining the amount of computer help services needed is an essential task that must be carried out separately for each organization. In the case of Sacred Heart, the demand for computer support exceeded the supply which resulted in the majority of their problems.

A study performed in a North Carolina School System saw the loan of laptops to a group of high school minority students for a one-year period [19]. The study gathered data solely in the form of surveys, with a few salient findings. The students in the study noted that the laptops increased their accessibility to information in general, as well as their ease of locating information. They also noted that the laptops allowed them to work at home, which was beneficial because it was where they spent much of their time and because it was a quiet environment. Asked via survey, 95% of students stated that the laptops had "been of value to them" and stated that their primary uses of the laptops were (with some overlap) internet access, communication, and information retrieval. Ninety percent of students surveyed indicated that having the laptops had helped them become a better student and eighty percent indicated that the laptops helped them increase their grades. Parents' opinions were also sought, with 91.7% of them stating that the laptops were of use to their child, 75% citing an increase in learning and resultant enthusiasm on the part of their child. While these findings are based upon surveys alone, they do suggest a high degree of enthusiasm for laptops by these high school students and their parents. This enthusiasm itself, even in the absence of a direct effect of the laptops on performance, may result in increased learning. Given their similarity to laptops, tablets could also be expected to meet with such enthusiasm.

Acadia University in Wolfville, Nova Scotia, as part of an IBM partnership, provided laptops to each of its 4000 students and faculty. A study [29] concerning the use of technology in one business course at the school revealed, via survey, that students experienced moderate to negligible changes in their attendance, preparation for class, study habits, and on-task in-class behavior. While these surveys pertained to the use of technology in the class in general, the laptops constituted a major part of that technology. Students also stated that they wrote personal ICQ[6] messages and accessed the internet for personal reasons during class and that they were able to do so without being noticed because the instructor expected them to be online in the class. All students identified web research as being of the largest benefit, specifically because the efficient retrieval of information aided them in their case studies. While the use of laptops in this study differed significantly from the use of tablets in the Paperless Classroom, it nonetheless points out the potential benefits of having on-demand web access as well as its potential to distract students during class.

Newhouse and Rennie [35] describe a laptop program in Perth, Australia, in which students in a school (which included both middle and high school students) were all

[6] *ICQ* is an instant messaging system, similar to AOL Instant Messenger. The name stands for "I Seek You."

required either to purchase laptops or to lease them from the school. A significant amount of data were collected over a multi-year period, and these data resulted in some interesting findings. It was found, for example, that while most students' courses required a significant amount of note-taking, few students used their laptops for note-taking because "these activities did not lend themselves easily to using a tool such as a computer (in this case, laptop)." This finding would certainly seem to indicate that tablets, having all the capabilities of laptops as well as a stylus, would be a better choice for use in the schools in question. Had this study not predated the release of current-generation tablets (the laptops in question were distributed in the mid-to-late 1990s), they might very well have used tablets instead.

This study also details difficulties with the laptop program which were largely attributed to lack of student knowledge of computers, improper management of the laptops, and shortcomings in terms of teachers' classroom management. Students' perceived problems with their laptops primarily consisted of hardware difficulties including general lack of reliability (presumably meaning system stability), excessive weight of the laptops, their short battery life, and lengthy boot and shutdown times. Problems such as these are certainly hardware specific, although they are likely the same set of problems encountered with other hardware, with other hardware simply varying in the degree to which each problem is manifested. Many of these, such as laptop weight, are subjective but since these findings represent a fairly large sample, they can be considered serious issues facing a laptop or tablet-based program.

Since this study, some of the factors have changed. The weight of these students' laptops is almost certainly greater than the 3-pound tablets used in our project. Battery life can also be expected to have improved since this study because of general advances in power saving technology. While boot and shutdown times were not specifically addressed in the design of Tablet PCs, Microsoft did set aggressive limits on the amount of time tablets were allowed to take going into, or coming out of, power-saving sleep states. Features such as hibernation, which allows a machine to enter a zero-power state indefinitely while essentially retaining the contents of memory (by writing them to disk) provide the equivalent of extremely rapid boot and shutdown times. The issue of reliability, while hopefully improved since the time of this study, can not be said to have been eliminated completely in modern machines. It was specially noted in this study that of all the problems mentioned, the one which crippled students' use of the laptops most was the weight issue. Regardless of what the weight of these students' laptops might have been (the study did not specify), it is still clear that some threshold weight exists, beyond which it simply becomes undesirable to carry and use a so-called portable computer. This reinforces our notion, described in chapters 4 and 6, that portability is a critical attribute, one that merits additional investment.

Newhouse and Rennie [35] also mentioned that many students preferred using the school's desktop computers because of their color screens, larger keyboards, network access, and better CPU and memory. This reveals the fact, previously unmentioned, that students' laptops had black-and-white screens, and shows that students do indeed prefer viewing things in color, as argued in section 2.4. This clearly defines the color-based advantage of tablets over pen-and-paper. The comment regarding keyboards reveals one sacrifice that has to be made in order to have a portable machine—the screen and keyboard are proportionally smaller as portability increases. However, it can be expected that, on a tablet, the need for a keyboard is at least slightly reduced because of the availability of the stylus. The tablet's built-in wireless networking capability clearly handles the network access issue, and the final issue regarding power and memory is clearly no longer an issue with all tablets on the order of 1 GHz in CPU speed, and with a minimum of 256 MB of RAM, with 512 MB being more typical.[7]

Also mentioned in the Newhouse and Rennie study [35] were teachers' opinions regarding the program. Main problems mentioned included lack of access to electrical outlets, difficulty providing students with printouts, and students who did not bring their laptops either because they had forgotten them or because they were being

[7]While it is true that software and operating system power and memory requirements have increased alongside the improvements in each of these domains, the growth rate of the hardware clearly outpaces the demand of the software. One can imagine that these students' black-and-white screened, mid-to-late 1990s Macintosh laptops were quite lethargic compared to modern tablets.

repaired. The issue regarding electrical outlets once again shows that long battery life is a key feature to consider when selecting hardware. The issue with printouts was not fully explained but would, in any case, be simplified in there were no paper handouts, only electronic ones, as in the Paperless Classroom. The final issue is more or less unavoidable—rates of forgotten or broken machines can be reduced, not eliminated. It was also noted that the teachers who were more active in incorporating the laptops into the classroom activities were those whose course content allowed the word processor to be gracefully substituted for handwriting. This clearly illustrates that, all other things being equal, tablets would have been used more widely than laptops had they been available in this project. On a related note, it was found that the laptops were only used significantly in situations where the teacher was willing to change the operation of the classroom to integrate the laptops or where the teacher was at least willing to encourage and accommodate their use in class.

A study conducted by Russell, et al [43] describes the use of a stand-alone electronic word processing called the *AlphaSmart* in third- and fourth-grade classrooms. While these devices are limited in their abilities compared to laptops and tablets, and while the subjects are quite young compared to university students, one of the findings may still be relevant to the Paperless Classroom. The study investigated how different AlphaSmart-to-student ratios affected students' usage. Of particular import is the finding that when a one-to-one student-to-device ratio existed, as opposed to a less than one-to-one ratio, the teachers' use of technology in the classroom increased—the increase was particularly large for teachers who were disinterested in using technology specifically because a less than one-to-one ratio existed. Furthermore, it was found that student use of AlphaSmarts greatly increased when a 2:1 student-to-device ratio was changed to a 1:1 ratio. While it is difficult to imagine an implementation of the Paperless Classroom in which a less than 1:1 ratio of tablets to students was used, this nonetheless reinforces the notion that teaching and learning with technology is particularly effective when each student has his own device. Arguably, the benefits associated with having a 1:1 student-to-device ratio, such as the aforementioned increase in usage found by Russell, et al [43], outweigh the cost of additional devices required to establish the 1:1 ratio.

Pertinent to the notion of 1:1 access is a study [6] which explored the reasons why people customize their PCs and mobile phones as well as the effect such customization has on them. It was found that factors which influence students to customize their devices include their frequency of use of the device, their ownership of the device, their knowledge of, and ease in carrying out, the customization process, and the influence of peers, among others. The impact of such customization, among other things, is that it creates a greater sense of personal identity for the user, creates positive associations and "fun," and results in a feeling of control and ownership of, as well as attachment to, the device in question. This relationship implies that customization is more likely if a person owns the device in question. Secondly, such customization provides a host of psychological benefits which, in the classroom setting, would arguably translate into increased enjoyment of the use of the device and perhaps more frequent use as well. This model would also certainly predict that a 1:1 ratio of students to devices would result in greater customization. Furthermore, it predicts that actual *ownership* of a device is an additional facilitator of customization and the associated benefits. This provides one argument against providing students with university-owned machines—if students own their laptop, tablet, etc, then they may interact with and perceive the device in a different, arguably more beneficial way.

Thus, there have been a variety of studies concerning laptops and their use in education, some with potentially conflicting messages. However, these conflicts can be reduced using explanatory measures for each exceptional case—the Sacred Heart study, for example, may have resulted in such negative findings because of an overall lack of preparedness of the school for a university-wide laptop program. All in all, these studies suggest that any use of technology in education must be carefully planned and executed but that, despite a few tolerable and perhaps solvable issues such as battery life and weight, laptops carry a significant host of benefits to students, with the greatest benefits likely to be found when a 1:1 ratio of students to laptops is used. A number of these studies suggested, without any reference to (or knowledge of) tablets, that laptops may not be the best device to give to students. Because tablets allow students to take freehand notes, have in-built wireless capability, and emphasize factors such as battery life and portability, they are the likely candidate for use in education in the future. Finally, while both systems of funding tablets (having students buy their own or having the school provide them with a per-semester fee) were employed, there may be benefits from having students own their own device, or at least in having students keep the same device for their entire college career.

3.2.1 Ergonomics

One potential area in which tablets and laptops differ is their impact on the user in terms of ergonomics and the injury that can result from repetitive use of a device. Straker, et al [51] found statistically higher neck flexion and head tilt associated with laptop use, as compared to desktop use. They note the likely reason for this difference:

> "The independent adjustment of screen and keyboard is important to allow users to position the tactile and visual interaction components, in a way which encourages a good posture."

Since many tablets also feature a "laptop-mode" (see section 4.4), they are certainly subject to the same problem as laptops in terms of neck flexion and head tilt. However, since all modern tablets offer a "tablet-mode" or slate-only functionality they do, at least, provide an alternative form factor, one which may be better ergonomically but which is, in any case, different from that provided by a laptop. A tablet's ability to convert between these two modes is beneficial even if it were to be shown that each mode taken independently resulted in bad posture because alternating between two bad postures is still better than continually staying in a single bad posture in that the two bad postures will often be bad in different ways, effectively trading one type of stress for another, giving one area such as the neck or back region a break while another region undergoes stress. And this presumes that tablets used in "tablet-mode" are, in fact, as bad as laptops in terms of the stresses they place on the body.

3.3 PDAs

A technology related to tablets and laptops is the PDA (Personal Digital Assistant) and it merits at least brief consideration. A recent review [8] of PDA technology cites the advantages and disadvantages of this technology, as compared to other technologies such as tablets or desktop systems. The review notes that the PDA is weak in terms of power and software availability compared to laptops (or desktops or tablets), but states that those problems are less of a concern in light of their lower price, portability, long battery life, and the ease of developing software for PDAs. The review also states that the single largest limitation of PDAs is their screen size—typically only a few inches across, with web content, for example, typically assuming a minimum resolution of 640x480 for proper display. Also described is the problem of pre-formatted file formats such as (Adobe Acrobat) PDFs, which render an article or other document in an inflexible way—a way that is meant to mimic a full sheet of paper. Screens as small as those on a PDA simply weren't meant to be used in these types of situations, and while software advancements no doubt make the impossible less impossible, it is difficult to imagine what could make a journal article with diagrams or a PowerPoint presentation containing textual notes as well as figures truly usable on a 3" screen. Thus, while PDAs are incredibly portable and boast a very long battery life, and have a number of applications, they are not remotely suitable for use in the Paperless Classroom, and arguably should not be used as the sole and primary computing device for education at any level.

3.4 Wireless Technology

Another type of study pertains to the use of wireless-capable devices in general—such devices include tablets, laptops, and PDAs. Considering studies whose focus is wireless technology will be relevant to the Paperless Classroom since the Paperless Classroom is partly predicated on the use of wireless networking, not only for distribution of course materials, but for general student access to online content in an *anywhere, anytime* fashion.

In a general review of information technology in higher education, McLaughlin [32] describes what he believes will be the properties of IT devices in the near future—ease of access to information, ubiquitous access to information, and wirelessness (as a requirement for ubiquity), among others. Clearly wireless technologies will play a large role in education in the future, and understanding these technologies and their potential uses is important.

Chang, et al [9] state many of the ideas already expressed, namely that anytime, anywhere access to the internet is particularly helpful to students given the variety and depth of information available via the internet. Furthermore, the internet can be used to provide a customized set of materials for a course, allowing instructors to make content of their choosing available to students. Chang, et al describe an *Ad Hoc Mobile Classroom*, that is, one which consists of a wireless network that is created at an arbitrary location because it is constructed using an Ad Hoc method: Devices in the network are all interconnected using their wireless adapters but no stationary unit such as a router or access point is required. Thus, an Ad Hoc network can be created outside as well as in a traditional classroom. The claim is that the Ad Hoc system described in this study allows greater flexibility in the choice of learning environments, and while our Paperless Classroom has chosen to remain fixed, within an indoor classroom, the potential for wireless technologies to create mobile classrooms certainly exists.

This study describes a general system which could have been implemented using any wireless-equipped technology, but was implemented and tested using PDAs. The system consists of a technology similar to the Stellar system used in the Paperless Classroom—a set of components, collectively referred to in this study as an *eSchoolbag* [9], consisting of electronic books and other materials which can be downloaded directly onto the device via the wireless network. Also described in this study is a characterization of the critical elements of the mobile learning—the mobile device, the communication infrastructure, and the learning activity model. In the case of the Paperless Classroom, these correspond to the Tablet PC, the wireless network at MIT, and standard, indoor classroom-based instruction. The Chang, et al mobile classroom is strikingly similar to the Paperless Classroom, although they do mention some features we chose not to implement such as instructor control of students' display. While this might be necessary in an Ad Hoc situation where there was no master display, in the Paperless Classroom, the instructor has a tablet connected to a projector and is capable of showing students information that way, with no need to control what appears on their individual screens. Although the study does not present formal findings on the usage of their system, it does indicate that other systems under consideration are similar to the Paperless Classroom and differ more in terms of implementation details than in terms of underlying ideas.

Wireless technology does carry with it a few problems, however. A project at Suffolk University saw the introduction of a number of wireless-equipped laptops in one of the university's libraries [13]. In addition to citing the three most common problems with their laptops (broken floppy drives, reduced battery life after extensive use, and broken hinges), as well as estimating a 2-year lifetime for the laptops they used, they noted some issues with their wireless network—namely, while the maximum bandwidth of each 802.11b wireless connection is 11 Mbps (11 million bits per second), their wireless hubs divided this bandwidth amongst all the connected machines, the result being poor network performance in real-world conditions. It was further noted that despite these speed-related problems, students still preferred the mobility provided by the wireless network over the speed provided by regular wired ethernet connections. However, wireless problems were the largest source of technical problems for students in our study of the Paperless Classroom. Furthermore, wireless networks have security vulnerabilities not present in wired networks, and their mobility in network terms may be of use to adversaries [39]. Despite these difficulties, wireless networks, along with the tablets themselves, are the very underpinning of the Paperless Classroom and our study seems to indicate that the benefits are well worth the drawbacks.

While wireless networks referred to thus far were assumed to IEEE 802.11b networks, there is at least one alternative wireless networking technology currently available—a technology known as *Bluetooth*. Johansson, et al [20] perform a rigorous analysis of the differences between 802.11 and Bluetooth networks, with the Personal Area Network (PAN) in mind. This notion of a PAN is similar to the aforementioned Ad Hoc network—it consists of a group of wireless devices internetworked in close physical proximity. The PAN assumes no fixed access point is used and thus is useful more for situations where two or more individuals wish to share data or perhaps an internet connection and is not particularly meaningful for isolated machines. However, the possibility of instructors and students (or students and students) sharing data or collaborating using a PAN exists, thus a brief review of these findings is warranted. It was determined that for use in a PAN, Bluetooth is generally better because of its lower cost and power consumption, as compared to 802.11, although recent improvements in 802.11 technology may reduce both of these differences. This study also describes a tradeoff that exists between these two technologies—Bluetooth is characterized by its ability to maintain network stability while an increasingly large number of nodes (e.g. tablets) are added, while 802.11 operates at a higher speed. It is also noted that, unlike Bluetooth, the energy efficiency of 802.11 declines rapidly as the number of nodes increases because of the number of network packets that are dropped during transmission but that for networks with small numbers of nodes, 802.11 is actually the more energy efficient technology. A final observation is that 802.11 PANs, unlike Bluetooth PANs, do not necessarily distribute bandwidth equally between all nodes, thus reducing the chances that any given node can be guaranteed to receive the bandwidth it needs. It would therefore seem that when deciding whether to use Bluetooth or 802.11 for personal area networks, the most important thing is to determine the maximum number of nodes that will be interconnected at any given time. While this does not make it clear what the exact numbers might be, it is reasonable to guess that Bluetooth would be the technology of choice for a lecture hall filled with students (assuming that they were all within range of each other), while 802.11 would certainly be acceptable for, say, a small seminar-style group.

3.5 Technology in Teaching

There are a great many studies regarding the general use of technology in education and its impact on students. A number of these studies will now be discussed, along with their implications for the Paperless Classroom. They cover a range of loosely related topics that are all relevant to the Paperless Classroom and will therefore be presented in no particular order.

A study by Muir-Herzig [33] concerned the impact of technology on "at-risk" students in k-12 schools (that is, those students whose performance is quite low for any number of reasons). This study noted previous work which suggested that technology can help students' learning and improve their attitudes towards learning. The study also noted prior work which shows that high equipment costs, lack of understanding of and proper use of technology (on the part of teachers and presumably administrators as well), and testing methods which do not test for what students learn through technology use are all things preventing technology from being more widely used in education. This study found no significant impact on at-risk student grades or attendance due to teacher use of technology, student use of technology, or overall use of technology, where the technologies in question include computers, digital cameras, projectors, software, and the like. This nonfinding may have been due, however, to the way in which technology was used, not the degree to which it was used or even what types of technology were used. The implication for the Paperless Classroom is that simply providing technology is not enough—a plan must be in place which explains how students will be affected.

It is also useful to consider a historical perspective when planning projects such as the Paperless Classroom. Kalmbach [21] points out that the introduction of computers into the classroom can be compared to the past introduction of typewriters into the classroom and concludes that it is crucial to clearly determine the expected advantages of a particular use of technology in the classroom, basing decisions on the ways in which new technology reflects prior uses of technology, rather than basing them on the "allure" of the most recently developed technology. This finding agrees with the notion described above regarding the need to have well thought-out plan prior to implementation.

Fortenberry and Powlik [15] reinforce this notion, but with a twist, stating:

> "Ultimately, the technology tools should become transparent as they engage the user with the material, enabling immersion in the learning process on an individual basis or as part of a community. Ineffective application (sic) of information technology include those that assume advanced levels of technical expertise in the user, are unreliable or difficult to maintain, or merely provide high-tech alternatives to traditional materials such as textbooks or blackboards."

These statements, while in general agreement with those previously mentioned, do contain one point of interest—the notion that technologies should not simply be high-tech alternatives to things like textbooks, blackboards, or, say, paper. It would be a misconception to think that Tablet PCs are unuseful simply because they are a "high-tech" version of paper—they are useful specially because they *are* high-tech versions of paper, allowing everything that can be done with paper to be done on the tablet while providing all the benefits associated with digital materials. It is the interaction of these two traits that is useful—either one alone would be of much less use. This reflects a typical notion that technologies in education must be fancy or offer some functionality not currently possible—this is untrue, depending on what is meant by "functionality." In a sense, the tablets do offer new functionality in that they allow handwritten documents to be easily stored and retrieved, backed up, shared, etc. But on the other hand their principal role is to help users do the exact same thing they already do—write with a pen. Their vast computational speed, videoconferencing ability, networkability and other traits aren't the focus during a typical day in the Paperless Classroom, and a system which attempts to make use of all of these in some novel way is not necessarily better than a system which maintains the status quo, albeit a digital status quo.

Another salient study [31] concerns the use of computer-based assessment (CBA).

The study notes the presence of previous work [28] showing that college students with less prior computer experience performed worse on a computer-based math test than did students with more computer background. It was noted, however, that even minimal training may have significantly reduced this gap in performance. Another study [] linked keyboard skill to performance on some types of computer-based tests, with the subjects themselves citing their lack of keyboard ability as a possible factor hindering their performance. This study further notes that studies show that computer anxiety is highly related to prior experiences with computers, those associated with computer classes, for example—these facts are related to the notion of subjective versus objective computer experience—while most studies focus on objective measures, it is actually the subjective experiences that result in computer anxiety, and that anxiety can be sufficiently distracting to reduce performance on computer-based tests. While these facts mean that there are, at least for some individuals, certain challenges associated with computer-based testing, this study also notes that there may be significant benefits associated with computer-based testing. Children, for example, were more attracted to computer-based tests, perhaps because computers are perceived as less threatening than the paper-based alternatives.

While the Paperless Classroom has not, thus far, included computer-based testing (by use of the tablets), it is a future possibility and it is therefore important to consider the implications of moving to a computer-based testing system—it may give those with prior computer ability an unfair advantage, resulting in test results which do not accurately measure the intended test subject matter. However, it is noted that even brief computer training or new positive experiences with computers can reduce computer anxiety and this may make accurate computer-based assessment feasible. This brings up another important point: Even if students in the Paperless Classroom continue to be tested on paper, their anxiety associated with computers might affect their performance during lecture or study outside of class. Since students volunteered to receive tablets, this was probably not a major problem, but if students were required to have tablets, then there is the issue that some students might have no choice but to engage in an activity which lowers their performance compared to what they would achieve with paper. However, even in upcoming semesters of the Paperless Classroom in which no paper is to be distributed, students will still have the option of refusing a tablet and printing out materials by downloading them from Stellar.

On a related note, Dickhäuser and Stiensmeier-Pelster [11] describe gender differences in the use and perception of computers, citing various studies showing such differences, including the findings that males are more interested in computers and have greater confidence with regard to computers, with females more frequently showing signs of helplessness. They cite further studies showing that boys have more access to computers in schools and more frequently pursue computer use than girls—they also take more computer classes, participate more often in computer camps. They also mention the problems these differential tendencies might cause—girls who are less confident in their computer use may be less motivated to use computers, inside or outside the formal course setting. They note that the converse is also true—a high self-concept of computer ability may well result in more extensive computer use. As part of their study, they found that girls had lower scores on each of these scales—computer-related self-concept of ability, computer-specific expectation, and computer use. They also cite a study [17] which indicated that females more frequently think of the computer as a tool while males think of it as an "experienced partner." This may be related to the notion regarding customization of devices (see section 3.2) which stated that customization of a device (e.g. a computer) leads to an attachment to that device. On a related note, Goos, et al [16] found that computers may be particularly good at facilitatating the communication and sharing of knowledge when they are treated as a partner or extension of self. Perhaps this notion of attachment exists in the long-term—attachment to computers in general, and positive feelings towards them, may result from past experiences with computers. These findings indicate that females have a different self-concept of their computer ability, one which does not necessarily indicate an actual deficiency in ability. The implication for the Paperless Classroom is that, without explicitly differentiating the sexes, it would be prudent to identify those students, male or female, who have particularly low confidence with computers and to recognize that their confidence level is not necessarily indicative of their ability level or their potential for ability. This also suggests that some students may not have volunteered for a tablet because of low self-confidence with computers even though their computer ability is, or could quickly become, more than sufficient.

Palmer notes in his study [37] of computer usage at an Australian University that applications most commonly used by students are Microsoft Word and other Microsoft Applications and web browser applications—this reinforces our notion that Microsoft Office is a highly demanded application and should be installed on each tablet used in the Paperless Classroom. Palmer also notes that some students do not consider the presence of an on-campus computer lab as constituting "access to computers," and further mentions a previous study which showed that computer access at home is linked to academic achievement as well as attitudes towards information technology. These findings may support the notion that having anytime, anywhere access to a computer is beneficial partly because access to computers at home is critical and access to computers at specific locations on campus is not always desired. If this is the case, then it is another argument for introducing more tablets into use while reducing the number of public computing machines in universities.

Alonso and Norman [1] describe the different forms of control that can take place in a technology-enhanced classroom—they define such a classroom as a place which provides each student with their own networked workstation, allowing students to view lecture notes and take notes on-line, and access relevant software during lecture—a description which certainly fits the Paperless Classroom. They distinguish between *Learner Control* in which the student "has active control over his/her display and can move through the lesson at will, thereby becoming an initiator of his or her own workstation activities during the lecture" and *Instructor Control* in which the teacher "has active control over the display and the student is a passive observer." Interestingly, the Paperless Classroom provides both of these types of control. Learner control is provided because each student has control over his or her own tablet, and instructor control is provided because the professor controls what appears on his tablet and projects his display to a large screen for all students to see. Ultimately, students can choose whether to look at the instructor's screen or their own, but generally the two will coincide, which brings up an issue mentioned in this study regarding synchronization—namely that there is the concern that students will get lost if they are in control of the system. The Paperless Classroom solves this problem by providing students and instructor with the same set of lecture notes and using Windows Journal to display them. Since Journal displays its page number for all to see, reestablishing lost synchronization with the Professor is easy, which also points out the lack of the need for full-fledged instructor control, something which is often suggested in technology-enhanced projects. Since students have an easy means of staying on the same page as the professor, it makes more sense for them to have full control of their own display. Students may have good reason to be on a different slide than the professor—if they remember something they want to change on a previous slide, for example—and so allowing the instructor to arbitrarily control their screens would not be a good idea. While Alonso and Norman cite another study showing that learner control is better for knowledge review but not as good for knowledge acquisition, this finding would seem to be questionable given the above arguments, specifically in light of students' need to take notes in the fashion they deem appropriate during the knowledge acquisition process.

Baylor and Ritchie [4] describe some findings that pertain to the acceptance and spread of technology in education, noting that teachers who are open to change, whether self-imposed or imposed by administration, adopt technologies to increase students' learning and that, in the process, their technical abilities and morale increase. They also note that administrators who actively pursue the use of technology in their institutions are far more effective than those who limit their efforts to the verbal domain. These findings suggest that Tablet PCs will be embraced by instructors who are flexible in general and that these instructors will increase their use of tablets in a way that is particularly effective when coupled with genuine administrative support.

Shaw and Marlow [47] reinforce this notion, finding in their study of attitudes towards information and communication technology (ICT) that males were more comfortable with ICT than females. They also showed that first-year students were more positive towards ICT than second- or third-year students. An additional finding supports a notion discovered in section 8.2.10, namely that students with positive attitudes regarding one aspect of ICT tend to have positive attitudes regarding other aspects of ICT. They conclude that providing a positive ICT-related experience might bolster a student's attitude towards ICT in general. Also of interest is their finding that students in their study preferred traditional, teacher-centered teaching methods and were not comfortable learning with an on-line environment, finding it too impersonal. Hopefully, the Paperless Classroom combines the best of old and new by using new technologies to improve existing pedagogical methods.

One rather large branch of information and communication technology is the internet; studies of the use of the web in education are relevant to the Paperless Classroom because the Paperless Classroom depends on the internet for its distribution of course materials. Ward and Newlands [53] describe an experiment which replaced selected courses at Aberdeen University with web-based content, eliminating in-person lecture completely. Although the Paperless Classroom retains in-person lectures in addition to making use of the web, a number of their findings are still pertinent. Ward and Newlands [53] found, for example, that students accessed course materials during a wider variety of times with the web-based system and experienced few technical problems which prevented them from accessing material. They also found that the web-based materials saved them time (although the reasons might not be compelling—students may simply not have spent much time studying, for example), noting, however, that students partially defeated the purpose of the experiment by printing out materials rather than solely viewing them online as was intended.

Students in the Ward and Newlands study [53] cited the main advantages of the web-based system as being "richer learning resources" and increased choice in terms of when they studied and at what rate they studied. The main disadvantages cited included loss of contact with instructors and other students and inadequate access to computers. The Paperless Classroom suffers from neither of these drawbacks because it preserves in-person lectures and provides a tablet to each student. The study also found that computer ability did not correlate with computer attitudes, something which is reminiscent of the previously mentioned fact that females' self-perception of computer ability is not necessarily an indicator of their actual ability.

Students were also asked what should be done in the future—11 students thought the web-based system should serve as a substitute for face-to-face lectures, 23 students said it should be a back up source of lectures, five students indicated that the web should mainly provide supplementary materials, and six students thought the web-based system should provide back up lectures and supplementary materials. These suggestions, in fact, indicate that the Paperless Classroom had the right idea—use the web to enhance ease of access to and quality of course materials, but don't use it to replace lectures and the personal contact with instructors and students.

Smeaton and Keogh [49] provide a fascinating account of another web-based experiment—they made audio recordings of lectures for an entire course, providing a set of lecture slides which automatically synchronized with the audio, resulting in a web-based course that was basically identical to the original course, but with synchronized slides instead of face-to-face contact with the lecturer. Using this system, students could access any lecture they wanted whenever they wanted and simply showed up for the examinations. Students' performance with the web-based system was compared to that of students who had taken the same course prior to the experiment. Interestingly, no significant differences between these students' performance (in terms of final exam scores) was found—virtual lectures and standard lectures resulted in the same grades. Additionally, there was no significant effect on the grades of students taking the virtual lectures due to their prior computer experience or their usage rates or usage patterns of the web-based system. They explain this lack of effect, in part, by stating that good attendance in standard lectures does not guarantee high performance nor does poor attendance necessarily result in low performance. It is possible that students are best characterized not in terms of how much they must study to achieve a given mark, but rather in terms of what mark they choose to get by studying. Certainly there are those students who shoot for an A and simply can't get it. But there are also those who can easily get an A and don't bother to put in the required effort. Students who want high marks will tend to get them and the amount of time they spend studying doesn't correlate with their grade because they put in whatever amount of time is required to achieve their self-set performance goals.

3.6 Note-Taking

Since the primary function of the tablets in the Paperless Classroom, in the end, is the viewing of course material and the taking of notes, a robust understanding of the impact of note-taking on students, on their performance specifically, is warranted. Literature related to note-taking is extensive, no doubt because note-taking implements have been around for some time, and because note-taking has been used in educational contexts for some time, at least compared to, say, computers.

Dewhurst, et al [10] found that students stated that their main purpose during lectures was to take decent notes, although they also mentioned a preference for receiving pre-printed notes over simply listening to lecture and taking notes themselves. This preference indicates why understanding note-taking fundamentals is particularly important when discussing the Paperless Classroom. If students have electronic versions of the lecture slides, some might argue, then what is the point of taking notes at all? In our particular case the point is somewhat moot because the lecture slides used in our subjects (9.01 and 9.14) contain relatively little information and serve mainly as an outline. Passing the class based solely upon study of the lecture slides, for example, would be quite difficult. This does not matter, however, for one can imagine handing students beautifully formatted fully complete lecture notes—essentially a textbook which corresponds one-to-one with material taught in lecture. The question is, in such a situation, would there be a need to take notes? Equivalently, assuming that digital materials were being used, would there be a need to use a Tablet PC, or would a laptop do? The purpose of this section is to answer that question by referring to formal literature on the subject of note-taking.

Slotte and Lonka [48] describe an experiment in which high school students were asked to take notes using their standard note-taking practices while reading a philosophical text—these students were later asked to write essays based upon the text. Half of these students were allowed to use their notes during the essay writing, and half were not, and each group was told in advance whether or not they would be able to use their notes during the essay writing. The experiment showed that students who were told in advance that they would not be able to use their notes during the essay writing task took significantly fewer notes, and lower quality notes, than students who were told they could use their notes during the essay writing task. They also found that students who took more thorough notes performed better on the writing task than those who took less thorough notes, with the worst performance corresponding to students who took no notes whatsoever. The logically result, that students who were told they could use their notes during the essay task performed better, was also found to be statistically significant. Another conclusion was that students who take notes that are not only extensive, but are also of high-quality, can be expected to perform better when extensive "deep-level" processing of the source material is required.

While these results pertain to note-taking during students' reading of a text, they may bear some relation to note-taking from lectures. Slotte and Lonka do, however, cite prior work which indicates that simply taking notes without reviewing them does not necessarily result in better performance than merely listening to a lecture without taking notes in the first place. One suggested reason for this is that some students taking notes during lecture may not process information before writing it down, rather, they copy things verbatim. It would seem that by removing synthesis from the note-taking act, students may eliminate the benefits due to the process of note-taking, although the benefits of review may still be somewhat intact. Slotte and Lonka cite prior work which shows that students are notoriously bad note-takers (specifically in terms of their organization) and mention one means of inducing students to take better notes—providing them with opportunities to review the notes in the future.

This is relevant to the Paperless Classroom because the tablets, as will be suggested by our study, provide students with greater ease of access to their notes, thus the benefits of high quality notes should be even greater to students using tablets, and therefore the motivation to take high quality notes in the first place should be increased. Another way to improve the quality of students' notes is to give open-note (but perhaps closed-book) examinations. Slotte and Lonka note that, in their study, students' notes were not generally verbatim copies of the text, whereas prior work regarding lecture note-taking did show verbatim copying. This difference, as Slotte and Lonka imply, may be due to the modality of the source material, which affects the ease with which written summaries can be formed. Summarizing from text may be easier than summarizing from the spoken word. These differences between note-taking done in lectures and note-taking done from reading a text must be kept in mind when reviewing studies concerning note-taking. The Paperless Classroom is primarily concerned with the former.

DiVesta and Gray [12] were the first to make the formal distinction between *encoding* and *storage* functions of note-taking. *Encoding* refers to what happens during the note-taking act while *external storage* refers to existence and use of the notes that result from the note-taking act. Encoding and external storage are also referred to by some as *process* and *product* respectively—that is, the note-taking process, and the product that results—the notes. DiVesta and Gray state their belief that notes which are taken solely for their storage-related benefits do not result in the greatest learning because they are taken in a "mechanical" fashion and provide a false sense of security—a feeling that having notes is a substitute for studying. They argue that encoding, on the other hand, is beneficial because it allows the student to 'link the material to his existing cognitive structure—to make it meaningful [to him].' To determine the impact of note-taking, they conducted an experiment in which subjects listened to a recording, with half being allowed to take notes, the other half only being able to listen. They found that the subjects who took notes performed significantly better on a test of recall. An additional finding was that note-taking was the only variable they measured which increased scores on the multiple-choice section of their test. They also draw upon their results to suggest that educational instruction should place an emphasis on note-taking, immediate chance to review, and subsequent testing procedures. Having found some positive effects of note-taking, DiVesta and Gray provide a characterization of the note-taking process:

> "The transformation is one of acting on the incoming information, sifting out relevant material, and organizing important content which is then recorded by the learner. The increased attention given to these concepts while taking notes increases the probability that the concepts will be retrieved even though there is little chance to review the notes immediately after studying." [12]

The implications of this study for the Paperless Classroom are that, if note-taking does indeed increase recall of material, then it is a valuable part of the educational process. This by itself does not suggest that tablets are any more suited to note-taking than laptops, but does support the general need for some sort of note-taking device. Additionally, there may be an interaction between the benefits afforded by note-taking and those afforded by the use of digital materials—that is, having electronic documents and taking notes may be significantly better than either one in isolation.

A study of the effects of different note-taking formats, performed by Kiewra, et al [23], builds upon the initial efforts of DiVesta and Gray. They cite prior work which showed that the benefits associated with the process of taking notes are "limited" whereas the benefits associated with the product are substantial, with students nonetheless using both functions—that is, students take notes *and* they use them later. They also refer to a prior study [25] (to be discussed in detail later) which indicated that students are extremely poor note takers, which would seem to suggest that the process of note-taking may be lacking in its effects partially because students take notes improperly, that is, in a way which does not benefit them as much as it could. They continue this discussion by pointing out previous studies which indicate that reviewing notes results in higher performance than not reviewing notes, something which supports the notion that the storage aspect of notes is beneficial. To further determine the effects of the encoding and storage aspects of note-taking, Kiewra, et al [23] created an experiment which focused on determining the specific impact of different note-taking formats, noting the existence of three formats discussed in the literature—the conventional, outline, and matrix formats. Those formats will now be described.

Conventional note-taking is defined in most cases to simply be what ever notes the note-taker would take without external influence and generally consist of notes taken in a sequential ordering which follows the order of material presented in the lecture or text which notes are being taken from. Outline notes may also follow the order of lecture material, but contain headings and subheadings which organize ideas into distinct categories. Finally, matrix notes consist of a two-dimensional grid with one axis containing headings and the other axis containing another set of headings or subheadings. Notes are taken in a given cell in the matrix if the idea in question pertains to the headings both the row and column to which it belongs. Matrix notes are therefore characterized by their innate ability to help the note-taker form associations between different concepts. Kiewra, et al cite prior work which points out that two-dimensional representations like the matrix are computationally efficient because they result in an automatic spatial grouping of related concepts. It is further pointed out that the interconnection of ideas, as accomplished in either matrix or outline notes, results in an improvement in performance of tasks that require information from disparate areas to be combined. Patterns and relationships exhibit themselves much more readily with a relational note-taking system.

The Kiewra, et al experiment determined that notes taken in one of these more powerful formats does improve performance when compared to the conventional note-taking style. They conclude by stating that educators should encourage students to take notes using either the outline or matrix format.

These findings are most relevant to the Paperless Classroom—since conventional notes generally consist of long chunks of text, oftentimes copied verbatim from the source, a laptop would be a suitable note-taking device, assuming that the conventional note-taking format was to be used. The outline format, while not incredibly difficult on a laptop, particularly when using software which is intended to create outlines, such as Microsoft Word, lends itself quite nicely to the Tablet PC. Headings and subheadings can be easily created, space can be added or removed, all in a manner which is natural and does not depend on software other than the primary note-taking application, Windows Journal.

The matrix format, on the other hand, is arguably difficult to create on a laptop. A spreadsheet grid from Microsoft Excel or a table from Microsoft Word might be useable for matrix note-taking, but the tablet immediately lends itself to matrix-style note-taking. A grid of arbitrary cell size can easily be created by hand, and it is even possible to save a template for later use. Ultimately, it may be found that a new note-taking system or a hybrid of existing systems is preferable, and regardless of what that system calls for, the Tablet PC is capable of handling it. Furthermore, this discussion hasn't even considered the notion of creating graphics and drawings during note-taking, but that topic will be considered shortly. A few more studies of note-taking warrant attention.

A related study [24] by Kiewra and DuBois considered what might happen if students were *given* notes in one of the three aforementioned formats. Students still watched a (videotaped) lecture, but did not take any notes of their own during the lecture. The goal of this study was to isolate the function of storage by removing the process effect altogether—that is, students did not take notes, but they were provided with notes. As part of their motivation for focusing on storage, Kiewra and DuBois cite a prior study which indicated that the main benefit of notes is in the storage function, not in the encoding function, but that, as shown in a previously study, students are terrible note-takers which reduces the benefits of the storage effect. To further support their claim that storage is the main effect, they cite prior work by Kiewra which showed that students who listen to lecture without taking notes and then study notes that are given to them afterwards perform better than students who take and review their own notes.

As the main purpose of their study, they consider the effects of the three different types of notes that have been discussed—conventional (in fact, a transcript of the lecture itself was given), outline, and matrix—and note that they would not expect any differences between the three note styles on tests whose sole purpose was factual recall. The justification is that the advantages of the outline and matrix formats lie in their facilitation of the formation of associations, and that strict factual recall only draws upon knowledge of isolated facts. They found that each of the three note-taking styles resulted in better performance than the no-note condition, and that the matrix and outline formats resulted in higher performance than the conventional format for some test types, namely those that required some synthesis of material to occur. They conclude by noting that none of the subjects were told *how* to use the notes they were given, with some students, in fact, converting the matrix notes they were given into a linear outline representation, probably undermining the benefits the matrix format would have afforded them.

These results would seem to cast a different light on the subject of note-taking—not only was it mentioned that one study showed that students performed better when they did not take their own notes and were simply handed pre-formatted notes, but it was shown that the benefits of formats such as the matrix and outline formats remain intact even when only the storage function of note-taking is in place. This would, on its own, seem to indicate that tablets might not be essential and that a Paperless Classroom could simply distribute electronic documents by placing them on the web after class, and having students review them from a desktop or laptop computer outside of class. However, this is not the final study under consideration, nor, as previously mentioned, for all its praise of the two-dimensional spatial coding of information present in the matrix format does it take into account any sort of diagrammatical note-taking, something would could prove to be a vital oversight, as will be discussed shortly.

In yet another study by Kiewra, et al [5], notions regarding encoding and storage were further explored in a series of experiments. In this case, subjects either took notes in one of the three formats previously described, or took no notes at all. Some subjects from each note-taking group were allowed to use their notes during a writing task, and some were not. Another experiment in the study revisited the issue of providing subjects with pre-made notes to isolate the impact of storage effects. Despite having found minimal impact due to encoding in the past, they cite a number of studies which showed that self-generated material (e.g. one's own notes) is more easily remembered than passively absorbed material, e.g. that which is had by simply listening to a lecture. They also cite material which states that the benefits of notes largely lie in their ability to facilitate an ongoing cycle of modification and re-visitation, with the greatest impact of modification taking place in outline or matrix notes, as opposed to conventional notes. On the other hand, they provide indications that note-takers' strategy is typically to take down as much information as possible, but not to organize that material—this forms the basis of their explanation for the small effect due to encoding—namely that without the review process which entails the existence of external storage, there is no way for organization to take place, and thus, at least in activities that require connections to be formed between various ideas, encoding alone can only have a minimal effect. The study in question, in fact, found this to be the case—for tasks requiring organized thought, taking notes but not using them during the writing task resulted in performance that was not significantly different from that achieved by not taking notes at all. They state, "The mere process of taking notes apparently does not lead to lengthier, more cohesive, or more coherent writing than does simply listening."

It was shown, however, that students who did not take notes but were given notes during the writing task did perform significantly better than those without notes, suggesting that the external storage function is indeed more significant than the encoding function in note-taking. *However*, it was found that the best performance, when all test types were considered, was achieved by the combination of encoding and external storage—taking notes or having notes are not as beneficial independently as they are when combined. Kiewra, et al explain this in terms of the principle of *encoding specificity* which states, in this case, that notes present during the note-taking act (e.g. during lecture) or notes present during review have less of an impact on memory than notes present on both occasions. In other words, the mere fact that the same set of notes is available to a student during these different time periods is important. Thus, Kiewra, et al concluded their study by stating that the quantity and quality of notes taken during lecture are connected to the length, cohesiveness, and coherence of essays written about that lecture, but that taking notes is not useful unless coupled with later review.

These findings are confirmed in another Kiewra and DuBios study [25] which, in addition to noting that, of 61 studies performed by Hartley [18] or Kiewra [22] or both, 35 were found to support an impact due to encoding alone, 23 found that encoding and only listening produced the same results, and 3 found that listening was superior to encoding (superior to taking notes). They also noted another group of 32 studies, also performed by Hartley [18] or Kiewra [22] or both, 24 of which were shown to support the benefits of encoding plus storage (i.e. review of notes), with 8 showing no difference between review and non-review, and none showing a detrimental effect due to review. Thus it would seem that encoding alone may have a weak effect, as just over half of the studies were able to detect its impact, while encoding plus storage must constitute a fairly large effect since 75% of the studies were able to detect its impact. Kiewra and DuBios note previous work which shows that repeated exposure to material increases learning, and explain that this may be the primary reason why encoding plus storage is so much better than encoding alone—encoding plus storage consists of at least two exposures to the notes, whereas encoding alone only guarantees one. Another potential reason, one which may coexist with the first, may be that the *generative* effects of storage are much greater than those of encoding. The notion, touched on earlier, is that review of material results in much more synthesis and organization than the original note-taking process. Kiewra and DuBois refer to prior work which indicates that this may be because the act of note-taking, particularly note-taking in lectures, is rather demanding—attention must be paid to the lecturer as well as the details of the note-taking act, the note-taker may need to work quickly to keep up, and so on. The review process, on the other hand, is more relaxed and the reviewer can set his own pace.

This study also consisted of an experiment, not dissimilar to previous ones, that considered each of the three regularly mentioned note-taking formats in conjunction with the three conditions of encoding only, storage only, and encoding plus storage. As expected, the encoding plus storage group was higher in performance than the encoding and storage groups, the storage group outperformed the encoding group, but only for the test requiring synthesis, and the encoding group was not significantly different from the control group (those who merely listened to the lecture without taking notes or reviewing). Since the experiment also checked for interactions between variables, it was found that the encoding group did not benefit from using the outline or matrix formats, suggesting that their benefits lie mostly in their ability to facilitate synthesis, something which, as suggested earlier, took place predominantly during review, not during note-taking itself. While these results would seem to make the note-taking act sound unimportant, Kiewra cites his prior work which showed that students add to their notes during repeat viewings of lectures, with particular tendency to provide additional detail. Furthermore, as found in previous studies and this one, encoding plus storage is better than storage alone, which means that note-taking is indeed a beneficial part of the educational process, but one that simply doesn't seem beneficial on its own because review of notes is an equally necessary component.

Peverly, et al [38] also note that prior studies show that *macropropositions* (defined as the relationship between propositions) recalled by students are predominantly the very macropropositions present in their notes and performed an experiment that consisted of two groups performing a writing task—students who were allowed to study for the task and take notes, and those who had to study without taking notes, with none of the students being allowed to use their notes during the writing task, and both groups studying for as long as they liked immediately prior to the writing task. They found that the students who had taken notes had more macropropositions, more information, more correct text-explicit items, and greater study time than the non-note-taking group, although the increase in study time was by far the largest effect. The study also concluded that the more information that is processed by the student, with note-taking being one means of processing information, the more the student is aware of his level of knowledge, whatever it may be. One other finding they made was that the amount of information in notes negatively correlated with the background knowledge of the note-taker of the subject in question. While these findings should not be interpreted as evidence against the host of Kiewra, et al findings regarding the relative importance of encoding, storage, and their interaction, it does show that encoding alone can have an impact on performance. In this case, however, it was relatively short term recall that was under consideration and the results may or may not apply to longer term recall.

Stewart, et al [50] provide a completely different perspective on note-taking in a study which focused on optimizing the use of student and instructor time to maximize students' learning per unit time invested. While generally unrelated to the topic of note-taking, it found that overseen note-taking, that is, note-taking which is reviewed by the instructor and possibly graded, was the single most efficient task to have students perform in terms of its utility to the students per unit time invested by the staff. This is presumably because their choice of grading process for notes allows the instructor to go through notes quickly, while the work it requires the student to do is extensive, as are the benefits conferred by such work. While Stewart, et al mention an upcoming study dedicated to this notion of the efficiency of overseen note-taking as a pedagogical tool, no evidence of this publication currently exists.

3.6.1 Diagrams

Remarkably, none of the above studies mention the use of diagrams. The note-taking literature does not seem to consider diagrams to be an essential component of note-taking, but fortunately Larkin and Simon [27] provide an account as to why a diagram can be quite valuable, and although they do not mention note-taking, their conclusions should clearly apply to the creation of diagrams as well as they apply to the viewing pre-existing diagrams. They begin by stating:

> "Diagrammatic representations [...] typically display information that is only implicit in sentential representations and that therefore has to be computed, sometimes at great cost, to make it explicit for use. [...] In the representations we call diagrammatic, information is organized by location, and often much of the information needed to make an inference is

> present and explicit at a single location. In addition, cues to the next logical step in the problem may be present at an adjacent location. Therefore problem solving can proceed through a smooth traversal of the diagram, and may require very little search or computation of elements that had been implicit." [27]

Related to the notion of spatial layout in diagrams is the notion of topography which they point out—a diagram explicitly represents connections between various visual components, practically providing a formal specification of the various agents at work—which agents exist, how they are related, and the topology of all such relations. It is the spatial aspect of a diagram that lends itself so well to conveying this topographical relation between components in a system. Simon and Larkin point out, however, that sentential representations, while largely lacking these topographical properties of diagrams, have other means of expressing relationships, by means of temporal or logical sequences. A fundamental concept introduced during their discussion of diagrams is the distinction between informationally equivalent representations and computationally equivalent representations. The former are representations which contain exactly the same information as each other (rather, information which is equivalent), and the latter are representations which contain the same information *and* provide access to the same set of easily accomplished computational tasks. They use examples from physics and geometry to show that solving problems in the graphical (diagrammatical) domain can be much easier (in the computational sense as well as in the colloquial sense) than solving the same problems in the word-based (sentential) domain. I will, however, use my own example as theirs are somewhat involved.

To see a demonstration of the computational efficiency provided by diagrams, consider figure B-5 which contains a set of people, and relations between them. The relation, for example, could be X *likes* Y, with an arrow in the figure pointing from X to Y if the relation holds. Ask yourself any of the following questions and see which representation, the sentential or the diagrammatic, produces the answers faster. Example questions include *Who likes the most people? Who is the most liked? Which* *groups of people like each other, that is, have bi-directional, mutual relationship? Which people are not liked by anyone? Which people don't like anyone?* and *Are there any cycles, that is, are there any 3-or-more person groups in what might be described as a "love triangle" (or quadrilateral, and so on)?* The same information is represented in the text below (that is, the sentential representation and the diagrammatic representations are informationally equivalent. But are they computationally equivalent?):[8]

> The Borg like Catherine Janeway, who likes Ruslan as well as Ludmilla. Romeo and Juliet like each other, and Romeo likes Jon Anderson as well. Jon Anderson likes Deanna Troi, Prospero, Bill Bruford, and Bach. Deanna Troi likes Data, who in turn likes Rick Wakeman, who likes both Steve Howe and Chris Squire. Chris Squire likes Steven Soderbergh, who likes Akira Kurosawa. Bill Bruford likes Peter Greenaway, who likes Rick Wakeman, Steven Soderbergh, Prospero, and Spock.
>
> Spock likes Sarek and Sarek likes Picard. Picard, in turn, likes Riker as well as Bach. Riker likes Kirk, who likes Uhura. Uhura likes Steven Soderbergh. Prospero likes Othello, who likes both Bill Bruford and Picard. Caliban likes Beethoven, who likes Mozart, who likes Prokofiev and Picard. Prokofiev likes Brahms, who in turn likes Mozart. Quark likes Dax, who likes, and is liked by, Bashir. Bashir also likes Sisko, who likes Mozart and Othello. Bach likes Jon Anderson.

The comparison should make it clear that, despite phrasing the sentential representation as gracefully as possible, the diagrammatical representation explicitly points out relationships that would have to be found in the sentential representation by linear search, unless the reader is capable of maintaining a mental representation of the entire scenario, in which case Larkin and Simon would rightly argue that the

[8]Note that this figure intentionally avoids using to color in order to focus on the properties of the spatial layout of diagrams. Color, as is argued in section 2.4, provides additional information in both diagrams and text, and its use in figure B-5 would likely have made drawing inferences about relationships between people in the diagram even easier.

mental representation would probably be a diagrammatical one, although this is only an intuition on their part and on mine. The example above was actually something of a best case scenario for sentential representations because, as Larkin and Simon point out, one problem with sentential descriptions of problems that normally belong in the diagram domain is that they lack the proper symbols for referring to things. In the example above, each component had a name, at least some of which were highly memorable given any knowledge of famous people. However, in the physics and geometry examples Larkin and Simon use, the sentential representation has to use phrases like:

> "The first weight is suspended from the left end of a rope over Pulley A. The right end of this rope is attached to, and partially supports, the second weight. Pulley A is suspended from the left end of a rope that runs over Pulley B, and under Pulley C. Pulley B is suspended from the ceiling. The right end of the rope that runs under Pulley C is attached to the ceiling." [27]

The frequent need for labels A, B, and C clearly indicates that if these letters each occupied a single point in space, instead of being spread across various sentences, then they would, in a sense, only be referred to once—all information regarding A, B, or C would coexist at a single physical location. While absolutely no connection exists between these notions in the literature, this notion is reminiscent of the matrix note-taking format previously discussed—it represents relationships between items through their spatial proximity. Furthermore, the particular row and column a cell falls under convey information regarding that cell. Thus a common thread would seem to be that representations of information which use two dimensions are powerful because they can establish connections between different objects. Just as a three dimensional representation could be expected to associate three different features, one dimension associates only a single feature with itself—that is, it produces no association at all. And it is this association, this synthesis of different ideas, or this relationship among various objects in a system, that arguably facilitates learning and understanding.

Larkin and Simon point out that the benefits of diagrams are likely rooted in their taking advantage of the powerful computational machinery built into the human visual system. Diagrams which are "well-made" or "clearly understandable" likely receive such labels because they take advantage of this innate machinery, allowing vast amounts of information to be processed in, quite literally, the blink of an eye.

If there are any formal grounds on which to support the Tablet PC, it is these. The Tablet PC does not only allow color diagrams to be viewed, it allows them to be created with ease. Note-taking studies clearly indicate that students experience dificultly taking high quality, comprehensive notes, typically only recording about 30% of the material in a lecture [23]. While pre-formatted lecture slides may help alleviate this problem, there are still informational gaps to be filled in. Furthermore, there is evidence suggesting the note-taking process (encoding) may increase learning, particularly when coupled with subsequent review (storage) of the notes. While students rarely employ them, the best known note-taking methods make use of two dimensions rather than simply creating a concatenation of verbatim text. Furthermore, while it is generally said that diagrams contain more *information* than text, it is actually more accurate to say that they contain more *computation* than text, allowing inferences to be drawn instantaneously—those inferences account for what is informally referred to as the extra information in diagrams. But inferences are in a sense better than information—assuming that information is considered the raw data, the inferences are meta-data, facts about the data and their interactions. These interactions as shown in diagrams facilitate synthesis of ideas, association of seemingly disparate concepts, and an understanding of the topology of a problem domain. To say that these things do not belong in a student's notes is to say that ideas and understanding do not belong in a students notes. It follows that Tablet PCs are the technology of choice for the Paperless Classroom. Nevertheless, chapter 4 will consider the question *Why Not a Laptop?*—albeit on significantly less theoretical grounds.

Chapter 4

Why Not a Laptop?

This chapter will compare the features and capabilities of the Tablet PC to those of laptops in order to demonstrate why the latter are inadequate for use in the Paperless Classroom. This comparison is particularly necessary because so-called one-to-one programs in which an educational institution guarantees a computer to student ratio of 1:1 are generally most likely to use laptops, as opposed to PDAs or other computing devices. Essentially, the two best candidates for use in the one-to-one environment are tablets and laptops so a comparison is useful. While making this comparison, I will also provide technical information regarding the hardware and software of the Tablet PC.

4.1 Tablet XP

When comparing tablets to laptops, it will occasionally be necessary to refer to specific hardware or software. I will begin with a description of the new Microsoft operating system designed for tablets. Recall the fact, mentioned in section 1.2, that a recent effort on the part of Microsoft has significantly accelerated the development of Tablet PC software and hardware. On November 7, 2002, Microsoft released its new operating system, *Windows XP: Tablet PC Edition*, which I refer to as *Tablet XP*. Understanding modern tablets requires understanding the features made available in Tablet XP. Additionally, Microsoft created a set of hardware requirements for all tablets running Tablet XP[1] that basically created standards for digitizer resolution and accuracy, power saving capabilities, docking and screen rotation behavior, and physical connectors present on the tablets.

Tablet XP is basically just Windows XP Professional with extensions for the Tablet PC. The major software additions which come preloaded on every tablet running Tablet XP include *Windows Journal*, the premiere note-taking application for tablets, an on-screen keyboard that allows the user to type with the stylus if the tablet has no keyboard or if the keyboard is detached, a new icon in the system tray called *Change tablet and pen settings* which provides a standardized interface (i.e. independent of the manufacturer of the tablet) for performing such tasks as calibrating the digitizer, changing screen orientation and brightness, assigning behaviors to any customizable buttons on the tablet, and changing various options pertaining to the behavior of the stylus. Tablet XP also includes an application called *Sticky Notes* which allows the user to take handwritten notes on a collection of small notepads whose contents persist until the user deletes them, and one new Windows game called *Ink Ball* that requires the user to manipulate balls into holes using the stylus. Also built into Tablet XP are newly improved Microsoft voice and handwriting recognition engines, the latter at least being quite impressive though not perfect.

4.2 The Stylus

The most fundamental difference between a laptop and a tablet lies in the fact that the tablet offers an input method not available on a laptop. The device used to perform input is called a stylus and it is basically an electronic pen that allows the user to write directly on the tablet's screen. This is what allows the tablet to perform its paper-replacement duty.

[1]See http://www.microsoft.com/windowsxp/Tablet PC/Developer/hdwreq.asp

4.2.1 The Digitizer

Truth be known, the stylus alone would be inadequate; the Tablet PC itself needs a way of detecting the presence of the stylus and converting the user's input into digital information. This device, called a *digitizer* is always built into the screen because that is where the user places the stylus when writing.

There are different types of digitizers, as described in [42], and earlier tablets used a *passive digitizer* which is passive in that it requires the pressure of the user's pen stroke on the screen in order to detect input.[2] Tablets using this type of digitizer have a pressure sensitive layer embedded in the screen which converts coordinates of detected pressure into a digital signal which is generally sent to the computer via a serial connection. An interesting property of the passive digitizer is that since it only depends on pressure, it doesn't usually care what produces the pressure, so even a finger can be used to provide input. For this reason, computers using this type of digitizer are often said to have a *touch screen.* While this is convenient in some cases, particularly for those doing field work or law enforcement, it does have its drawbacks. First and foremost is the fact that since the digitizer accepts input regardless of the source, it will also interpret the pressure caused by a palm resting on the screen as input. Thus, if the user is writing with a stylus but resting a hand on the screen as one might do when writing on paper, the digitizer will not discriminate between the stylus and the palm. What digitizers generally do when multiple inputs simultaneously occur is to average the inputs[3], thus writing with two styli at the same time, one in the upper left and one in the upper right corner of the screen, would effectively be the same as writing with a single stylus in the center of the screen.

In the case of the palm resting on the screen, the digitizer will produce output somewhere in-between the point of contact with the stylus and the center of the palm, and the result is totally undesired output. Since, in our observations, it was quite difficult to write for any length of time without resting one's palm on the screen[4] so

[2]There are other types of passive digitizers as well, but tablets using passive digitizers generally use the pressure-based type.

[3]You can try this if you have a tablet or laptop with a touch pad

[4]It was possible, provided that the screen was small. We tried some devices that probably

we deemed tablets using passive digitizers as inadequate for our purposes.[5]

Fortunately, a new type of digitizer was becoming more widespread as we started work on the Paperless Classroom in mid-2002. This new digitizer, the *active digitizer*, does not depend on pressure at all, rather it directly detects (either with an induction coil or an active signal) the location of the stylus and converts it into digital coordinates. Confusingly, within the category of active digitizers, there are two different types of styli—*active* and *passive*, that is, those that do and do not have a power source (i.e. battery) respectively.[6] Regardless of the type of stylus, there are two key features of the active digitizer. First, it can detect the stylus even when it is not in contact with the screen—the user can still move the cursor with the stylus up to about half an inch above the screen. This behavior, called *hovering* is equivalent to moving a mouse across the screen without holding any buttons down. To perform the equivalent of dragging a mouse with a button depressed, it is necessary to move the stylus across the screen while it is in physical contact with the screen. The tablet does not use pressure to detect physical contact with the stylus. Instead the active digitizer receives this information from the stylus itself or is capable of detecting the distance of the stylus from the digitizer. The second feature of the active digitizer is that it only accepts input from the stylus and in fact will generally only recognize a stylus made by the same manufacturer as the tablet itself. This can be a nuisance if you lose the stylus, but confers the essential benefit of automatically ignoring palms. Thus the active digitizer was the only acceptable choice for use in the Paperless Classroom.

belonged in the Handheld PC category, with screens under 8" in diagonal. On these devices, it is possible to rest your palm on the surface of the device adjacent to the screen surface and still write anywhere on the screen. However, these devices were unusable for our purposes because of the very reason that their screens were too small.

[5]There was one interesting tablet, the Fujitsu Stylistic ST3500/ST4000 which used a technology called *palm rejection*. This technology presumably allowed the digitizer to check for and ignore any large regions on the digitizer that were activated by pressure, such as would be produced by a palm resting on the screen. I found this technology to work rather well, but the majority of passive digitizers do not employ this technology.

[6]The advantage of the active stylus (manufactured by *FinePoint*) is that it reduces overall digitizer power consumption. The advantages of the passive stylus (manufactured by *Wacom*) are that, without the need for a battery, they can be thinner, and also can contain a built-in eraser.

4.2.2 Stylus Capabilities

The actual benefit of having a stylus as an input device lies in the fact that it allows the user to interact naturally, using all of the skills already learned using a pen or pencil. These skills include regular handwriting, drawing diagrams, artistic drawing, and the like. Although the mouse is functionally equivalent to the stylus, almost no one has the level of coordination with the mouse that they have with a pen or pencil. Giving the user the opportunity to use these skills on the tablet opens up an entire universe of computer usage that was previously unavailable. The stylus is a very unconstrained input device compared to, say, the keyboard, because given the right application, it allows you to do whatever you want wherever you want, whereas the keyboard limits you to a particular set of symbols, i.e. the alphabet, numbers, punctuation, etc, and generally speaking these symbols must be placed one after another, left to right, top to bottom. While this is exactly what one wants when typing a document, it is a highly restricted subset of all possible modes of input and the stylus is significantly less restricted.

In the case of the Paperless Classroom, the goal is to replace all the functions of paper with a tablet, so a review of the functions of paper in our Neuroscience class is in order. In the paper-based system, students are given printed versions of the PowerPoint slides used in daily lectures and students then have the option of taking notes directly on the slides that the Professor refers to in class. With pen and paper, students can write anywhere, at any angle, with any text size, with any color (provided they bring colored pens/pencils), and are not restricted to text but can create freehand diagrams as well. Students taking notes highlight, draw arrows, circle, or underline, draw brackets or braces, and the list goes on. The stylus allows every single one of these things while the keyboard allows only a small subset of them, which it allows less intuitively. For example, it is generally impossible to circle something with a keyboard. And while it is possible to underline something, it is necessary to select the text to be underlined and then hit a special underline icon or keyboard shortcut to actually underline it. While an adept user can do this quickly, virtually every person alive is already adept at underlining printed text, and arguably capable of doing it even faster than the adept keyboard user (unless multiple lines of text are being underlined which is unusual).

Windows Journal

The stylus even has some capabilities that paper does not, but to discuss them, it is necessary to describe the specific note-taking software being used—in this case, the aforementioned Windows Journal. Windows Journal is a simple but very effective note-taking application. Its most crucial feature is hard to describe but instantly understood by Journal users—the act of writing is amazingly similar to using an actual pen in terms of the smoothness and responsiveness of the screen to user input. There are still some things that remind you that you aren't using paper—namely that there is less tactile resistance on the screen than on paper, i.e. the screen is more slippery, and ease of writing is somewhat compromised if calibration is not just right. However, overall, Windows Journal is an incredibly satisfying tool for taking notes and without it the tablets would not be nearly as successful as they are. Journal contains several toolbars containing icons (see figure B-6), the most important of which are the pen, highlighter, eraser, lasso, insert/remove space, and flag icons. Several of these tools have small triangles to the right of the icon which can be clicked, allowing the user to choose different options for each tool (e.g. pen/eraser size). The tools' names indicate their function except in the cases of the lasso which allows the user to select a region of text and the flag, which allows the user to place a flag object in the text to mark a spot as a special point of interest, making it instantly accessible via a menu in the future.

Besides allowing the user to use pens, highlighters, and erasers of varying colors and sizes as they would on regular paper (albeit only if the user had quite a collection of writing utensils)[7], Windows Journal provides some capabilities not possible on

[7]The value of producing and viewing notes and handouts in color cannot be emphasized enough. Perhaps the largest benefit afforded by Windows Journal is the speed and ease with which it allows the user to change pen/highlighter colors. Although some students do use colored pens/pencils, it was our finding that the majority would have liked to but did not because it was too inconvenient

paper. The majority of these are due to the fact that the document is a computer file, meaning that it can be instantly copied, sent to another person, and so on. Journal also provides some enhancements in the note-taking act—the eraser always erases perfectly and can erase entire words at a time using the special *stroke eraser*, the lasso tool allows large segments of text or diagrams to be selected and then copied and pasted, or deleted. On a regular page of handwritten text, inserting more text halfway down the page is more or less impossible, but in Windows Journal, text can literally be moved farther down the page to make room for inserted text. Furthermore, Windows Journal allows the user to search an entire document of handwritten text for a particular word—it accomplishes this by running its handwriting recognition engine on all the text in the document and finds words with surprising accuracy. Basically, all of the advantages that the word processor brought to typed text is now brought to handwritten material by Windows Journal. And Windows Journal is only usable with a Tablet PC and its stylus.

4.3 Portability

Students in 9.01 and 9.14 generally receive between one and two thousand pages of printed handouts.[8] The total weight of these handouts is at least twenty pounds, and while it may not ever be necessary for a student to take all of these handouts with them on a particular day, even a relevant subset of this material could weigh, say, five pounds especially given that a student who wishes to study with a study group or work on an assignment may not know which material they will need in advance. One goal of the Paperless Classroom is to reduce the physical burden of students while allowing them to carry around at least as many of their handouts and notes as they did previously. As mentioned in section 3.2, it has already been shown that one of the largest complaints made by students required to bring laptops to school

to purchase them or bring them to class, or because switching between them frequently took too much time.

[8]With about 20 pages of lecture slides and 20 pages of supplementary readings handout per class, and about 35 classes per term, for a total of roughly 1400 lecture slides.

on a daily basis is that they simply weigh too much. Tablet PCs should alleviate this problem because they generally weigh only three pounds, with the heaviest at around five pounds. Laptops as light as three pounds certainly exist, but they are few and far between and some weigh eight pounds or more.[9] While there are laptops available that are just as light as tablets, the vast majority are almost two to three times as heavy. It's important to note that the very laptops that are in the three-pound range are also the most expensive. This is important to remember anytime the claim is made that laptops are much cheaper than tablets—the rebuttal is that laptops of size and weight comparable to that of tablets are not nearly as cheap as the larger laptops. In any case, prior evidence has shown that portability is one of the largest factors in motivating or not motivating students to bring a laptop/tablet with them on a given day, and as it turns out, this notion was reinforced by our study of the Paperless Classroom. Thus portability can be considered a major advantage of the Tablet PC.

4.4 Flexibility

Related to portability is flexibility of use. Because the tablets are relatively light, it is possible to use them in a number of ways not nearly as feasible with laptops. For example, using a tablet while standing is quite comfortable because of its low weight and because of the fact that it can be written on directly without the need for a keyboard. While this is not specifically beneficial for students in the Paperless Classroom who will presumably be seated, it is nonetheless an advantage of the tablets that students might appreciate outside of class.

Another regard in which tablets are flexible is related to their form factor. The various Tablet PCs available on the market differ somewhat in their form factor, and I prefer to break these form factors down into three categories.

First, is the *pure slate* or just *slate*, which is just a screen with no keyboard at all.

[9]Dell's website indicates that their different laptop product lines have weights starting at 2.99, 4.98, 6.9, 7.22, 7.22, and 7.91 pounds.

The screen contains all the hardware needed for the tablet to function, i.e. the CPU, memory, hard drive, etc. The only way to use a keyboard with a pure slate is to use the on-screen software keyboard provided by Tablet XP or by attaching a USB keyboard or a docking station. The disadvantage of the pure slate is that a real keyboard is generally unavailable, and even when a USB keyboard or docking station is available, using the tablet under such circumstances can be clumsy compared to using a laptop or desktop. The advantage is that, given the lack of need for a keyboard, the tablet is extremely light and portable and very easy to use when cradled in one arm the way a clipboard would be held. This design is best for someone that will only seldom need a keyboard or someone who simply doesn't mind pecking away at a software keyboard with the stylus. Examples of manufacturers that provide pure slates are Motion Computing (also sold under Gateway's name) and Fujitsu.

Next are the tablets that have a permanently attached keyboard. These tablets are often called *convertibles* because they have a screen that rotates, allowing the tablet to transform between what appears to be a regular laptop and what appears to be a true slate. The difference between these and pure slates is that the keyboard is always available in a pinch but the tablet weighs a little more than it would without the keyboard. Some might also perceive it as a disadvantage to have to rotate the screen in the first place. This design is of course best for someone that will want to make heavy use of the keyboard. Both Acer and Toshiba offer tablets of this variety.

The third category is a cross between the first two categories because it has a screen that rotates, allowing the tablet to be used either as a tablet (i.e. with the keyboard concealed under the screen) or as a laptop, but the keyboard is actually detachable, allowing it to become just like a pure slate. One could also think of this type of tablet as a pure slate that simply comes with a keyboard that attaches in a really slick way. In any case, the advantage of this design is that you get the best of both worlds, but with one small catch—since the tablet has to be able to function without the keyboard, all of the hardware (e.g. CPU, etc) is inside the screen, just like on a pure slate, and unlike a regular laptop or the convertible tablets. The result is that, when used in laptop mode, the center of gravity is higher and the necessarily light keyboard does not provide enough ballast to keep the tablet from tipping over in certain situations. When used on a regular surface, it works fine, but actually using it on your lap is less feasible. Thus this design is probably best for someone that knows they want the pure slate capability but will also need the keyboard somewhat frequently. Compaq/HP is the only manufacturer to offer this unique design.

Thus, an advantage of tablets over laptops is that the latter two categories (i.e. all tablets except the pure slates) are more versatile in that they provide two different form factors, i.e. what I call *tablet mode* and *laptop mode*, for the user to choose from. This flexibility is made available virtually without trade-offs. The benefits of such flexibility are several—the user can work more efficiently by using whichever form factor is most effective at a given moment. Also, repetitive strain injury (RSI) could be staved off in part by switching between different form factors, allowing the user to change body and hand posture more frequently. It is known that laptops result in greater neck flexion and head tilt than desktops (see section 3.2.1), suggesting the need for some mode of use other than "laptop mode." Students, especially those who study intensely (as is often the case at MIT), are great candidates for RSI so I consider this a major advantage. It could in fact be argued that the tablet mode is more flexible than the laptop mode in terms of the number of different physical positions it allows the user to occupy. For example, a laptop with its keyboard is a clumsier object to hold than a tablet and the result is that fewer viewing angles and positions are possible because both the angle of the screen and the keyboard must be attended to whereas with the tablet, the angle of the screen is the only variable that needs adjustment.

4.5 A Variety of Disciplines

A major benefit of using tablets instead of laptops in the Paperless Classroom results from the aforementioned fact that notes taken with the stylus can be anything and can go anywhere, in any orientation, in any size, in any color. Notes taken with the stylus really can be anything the user wants, which makes the tablet useful for taking notes or doing coursework in a variety of disciplines whereas a laptop is only useful for taking notes or working on a given subject to the extent that linear textual notes are desired. For example, a chemistry student may argue that the laptop is helpful for taking notes in chemistry lecture, producing page after page of typed notes on the subject. But this really begs the question as to why a student would need page after page of textual notes. We sometimes refer to students who take notes in this fashion as *passive stenographers* because their role in lecture is to record every word the lecturer says, arguably precluding the possibility of the student's thinking about anything other than the note-taking act itself. If a transcript of lecture were required, then it would certainly suffice for one person to generate and distribute the transcript.

In any case, textual information is certainly not the only kind of information provided to a student in lecture, and even if we interpret it as the student's job to record everything said in lecture, a laptop still wouldn't be adequate to the task at hand. This is because most lectures, particularly those in science and engineering, are rich in visual content such as pictures and diagrams. They are also rich in content which is somewhat textual but not easily captured with a keyboard, such as equations. In fact, going down the list of MIT departments, I can provide examples of non-textual information a student taking notes in classes from each department would likely wish to record.

1. Civil and Environmental Engineering—equations, force diagrams, bridge designs, chemical formulae

2. Mechanical Engineering—equations, force diagrams, diagrams or schematics of mechanical systems, design drawings for a device

3. Materials Science and Engineering—equations, crystal lattice diagrams, molecular diagrams

4. Architecture—equations, floor plans, exterior and interior design graphics

5. Chemistry—equations (mathematical and chemical), molecular structures, valence diagrams

6. Electrical Engineering and Computer Science—equations, circuit diagrams, software block diagrams, explanatory diagrams for algorithms, mathematical notation for describing algorithms and their behavior

7. Biology—equations, cellular diagrams, molecular formulae, diagrams depicting genes and their interactions, DNA binding diagrams

8. Physics—equations, force diagrams (mechanical and electrical), diagrams of physical or electrical systems

9. Brain and Cognitive Sciences—equations, nervous system pathways, brain structures

10. And so on

All it takes is a moment of thought to realize that none of these things are intuitively or speedily doable using a laptop. While special tools may exist to handle some of the cases (for example equations can be created using a special equation editor), the special tools invariably require that the user have special training and in any case require much more time than simply writing things out by hand. The fact that using software would result in, say, beautifully formatted equations, is not relevant because the assumption is that the student wants notes for purposes of review, not because they intend to publish their notes in a journal.

A further benefit of the universal applicability of the tablet to all subjects is the fact that it can be used for all of a student's courses, both for purposes of note-taking and doing assignments. And since the tablet does not preclude the use of a keyboard, it can still be used for everything a laptop can be used for. The result is that tablet has the potential to be a single, all-inclusive, educational tool for the student.

4.6 Tablet Hardware

As a final comparison between laptops and tablets, I will briefly compare the two in each of the major areas by which computers are generally measured—physical size and weight, screen size, computational speed, memory capacity, disk capacity, ports and expandability, and cost. Inevitably the laptops will have an advantage in some areas, but it turns out that for our purposes, the tablet's advantages far outweigh them. I will compare both of the tablet models we used in our experiment (Acer and Compaq) alongside Dell brand laptops. Dell laptops were chosen because Dell's products are fairly well respected and should serve as a fair comparison. Note that while we only used Compaq TC1000 tablets in our experiment, both the TC1000 and newer TC1100 are considered in order to make a fair comparison—the TC1000 is a year older than the other items being compared.

4.6.1 Physical Dimensions

I already discussed weight differences in section 4.3. Although some laptops are just as light as tablets, tablets tend to be much lighter and are therefore much more portable. Since size for these devices correlates fairly well with weight, a similar relationship exists there as well—tablets are, by and large, much smaller, the Acer TravelMate C100 tablet having dimensions of 9.9" x 8.2" x 1-1.16" and the Compaq TC1000 (the TC1100 is nearly identical in its dimensions) tablet measuring in at 10.8" x 8.5" x .8" (without the detachable keyboard which adds some thickness) while the Dell Inspiron 5150, for example, has dimensions of 13.1" x 10.8" x 1.83". As stated earlier, small laptops do exist, such as the Dell Inspiron 300m, with dimensions of 10.8" x 9.2" x 0.96", but these are the most expensive laptop models with price tags just slightly less than tablets (cost will be discussed shortly).

Another benefit of having a smaller unit such as the tablet is that it fits on most classroom desks, including folding desks, whereas all but the smallest of laptops are cumbersome in this regard. This is discussed in greater detail in section 4.7.

4.6.2 Screen Size

Screen size is one area in which laptops, owing to their generally larger overall size, have an advantage. Even the Dell Inspiron 300m, a laptop of size comparable to that of the tablets, has a larger 12.1" screen. Small screen size is perhaps the single largest disadvantage of the Tablet PC, but it is not a critical disadvantage and most people find the 10.4" screens found on most tablets to be quite suitable. For those who disagree, it is worth noting that some tablets, particularly the pure slate tablets, do offer 12" screens. In fact, some newer tablet models, such as the Acer TravelMate C300 and 250PE boast screens as large as 14.1", with the obvious (and I would argue detrimental) increase in size and weight. However, the 15" or even 17" screens boasted by some of the larger laptops are certainly unavailable on tablets, and for the purposes of the Paperless Classroom, the tablets' advantages in size and weight are well worth the reduction in screen size, not to mention the benefits associated with being able to use a stylus.

4.6.3 Computational Speed

Speed is another area in which laptops have an edge, but as we've seen earlier, the gap becomes negligible once tablets are compared to laptops of comparable size. For example, the Dell Inspiron 300m, the closest in size and weight to our tablets, has a 1.2 GHz Pentium M (Centrino) processor while the Acer TravelMate C110 and Compaq TC1100 tablets have the same CPU running at 900 MHz and 1 GHz respectively.[10] While the laptop has the slight lead, it is important to remember that CPU clock speed is not nearly as much a limiting factor in computer performance as it used to be. Factors such as memory subsystem and hard disk performance are much more important now, and while direct comparative benchmarks are not available to me, it is likely that the memory and disk performance of these systems is quite similar despite the slight disparity in CPU clock speed. In any case, with the exception of the original Compaq TC1000 tablet (which used a Transmeta CPU to substantially increase battery life), all of the modern tablets[11] perform well within our expectations and those of our students. The TC1000 was generally decent in

[10] A less expensive 800 MHz Intel Celeron CPU is also available for the Compaq TC1100.

[11] That is, those running Tablet XP. We tested a number of tablets prior to the release of Tablet XP and their performance varied from abysmal to excellent.

speed, but on occasion it did feel a little slow. In any case, Compaq has resolved this issue with their current model, the TC1100. What ultimately matters is that for all but the most computationally demanding applications, all modern tablets are more than adequately fast.

4.6.4 Memory

As mentioned earlier, while no direct comparison of the memory subsystems of tablets compared to those of laptops is available to me, there is every reason to believe that models of similar size will have comparable memory systems. The memory systems of the tablets are impressive in their own right, the Compaq TC1100 having, for example, 512 MB of RAM from the factory with a maximum of 2 GB. The memory type is DDR SDRAM running at 333 MHz. And again, what really matters is the fact that the overall performance of the tablets is quite acceptable.

4.6.5 Hard Disk

While no disk benchmark data are available to me, it is easy to compare disk capacities and rotational speeds between laptops and tablets. The Dell Inspiron 300m, for example, ships with a 30 Gb 4200 RPM drive, while the Compaq TC1100 tablet ships with a 40 Gb 4200 RPM drive. They are both upgradeable to a 60 Gb drive, a 4200 RPM drive for the Dell, and a 5400 RPM drive in the case of the Compaq. Dell offers hard drives as fast as a 60 GB 7200 RPM drive and as large as 80 GB 4200 RPM drive, these are only available on the larger laptops. Thus hard disk size and performance would seem to be comparable for laptops and tablets of similar size (and not all that much different even if larger laptops are considered).

4.6.6 Expandability

Rather than comparing tablets to laptops in this regard, I will simply state that virtually without exception, tablets running Tablet XP have a healthy set of connectors and ports for expansion, at the very least including USB ports, a PCMCIA slot, headphone and microphone jacks, VGA output, built-in modem and ethernet, and docking capability. Some have additional connectors of interest such as the Acer TravelMate series which has a built-in firewire (IEEE 1394) port, or the Compaq tablets which have a built-in compact flash (CF) card reader.

Of special interest to the Paperless Classroom is the fact that all tablets running Tablet XP have built-in wireless networking capability.[12] It will turn out that our project depends on this highly, and while some laptops, including the Dell Inspiron 300m, have built-in wireless, it is not a guarantee as it is with the tablets.

4.6.7 Cost

If the tablets have one weak area besides small screen size, it is cost. The fact that they have all the features of laptops, have to be ultra-portable, *and* have to have a digitizer and stylus does drive up cost. However, manufacturers have priced tablets quite competitively, for to do otherwise would result in the failure of their products to sell. The result is that all of the benefits of the tablet can be had for a reasonably small additional price, when compared to laptops of similar size. If size is not used as an important criterion, then there is no contest because the bulkiest entry-level laptops can be had for literally half the cost of the tablets. For example, the 7.22 pound Dell Inspiron 1100 series begins at a mere $699.[13] However, the 4.98 pound Inspiron 600m series begins at $1299 and the 2.99 pound Inspiron 300m begins at $1449. The Acer TravelMate C110Ti can be had for exactly $1449 as well.[14] However, the Compaq TC1100 tablet is somewhat pricier at $1849.[15] (The older TC1000 no longer appears on Compaq's website, but can still be purchased from online vendors for under $1500.) In any case, given these limited examples, it is clear that one can have a tablet for between $0 and $400 more than a comparably featured laptop. For the purposes of the Paperless Classroom, there was no choice but to use tablets, but

[12]Some tablet models do not contain a wireless card, but each model at least offers a built-in wireless option, with most manufacturers including the wireless adapter in all of their products.

[13]As listed on Dell's web site.

[14]As listed on Acer's website.

[15]As listed on Compaq's website.

knowing that the additional expense wasn't terribly large was nice in any event.

4.7 Classroom Conversion

Another benefit of the Tablet PC results from its small size, flexible form factor, long battery life, and bulit-in wireless networking capability. The combination of these traits allows a Paperless Class to be held in any room, that is, a special room designed for tablets/laptops is not needed. Rooms intended to be used with a classful of students using laptops tend to require modification—power outlets must be installed at every seat, the desks must for a large contiguous surface in order to have adequate surface area to hold standard-size laptops. Wired ethernet ports may also be required as many laptops still do not come with built-in wireless. The tablets, on the other, are small enough to fit on any classroom desk—they can even be used when a desk doesn't exist at all because their form factor allows them to be in "tablet mode" which does not require a desk surface to be used comfortably. Their long battery life and built-in wireless cards preclude the need for electrical and network rewiring of classrooms, saving enormous amounts of money in installation and remodeling costs. This flexibility of the tablets, their ability to "adapt to their environment" should not be forgotten when estimating the cost of the Paperless Classroom.

4.8 Reliability and Durability

While extensive, long-term data is not yet available on the repair records of various tablet models, it is possible to estimate differences in reliability by visual and tactile inspection of the tablets as well as by examining the evidence available to us so far. The Compaq tablets have a harder, more durable screen than the Acer tablets, and feel less flimsy in general. However, both tablets use extremely lightweight components which is generally beneficial but also translates into decreased strength of the various components. The latches break on both Acer and Compaq tablets in roughly equal numbers. A Compaq battery falling only a short distance (about one foot) cracked and was not repairable. The left mouse button on the Acer has become loose, though still functional, on several machines. While almost all of the tablet keyboards are still intact, keys do sometimes become loose or fall off completely. In this regard, the Compaq has an advantage—no matter how badly damaged the keyboard becomes, the very worst thing that can happen is the purchase of an entire replacement keyboard. This is because, unlike the Acer, the Compaq has a separable keyboard unit, one which does not house any electronics other than those pertaining to the keyboard itself. Thus, while it is far too early to differentiate between tablets on the basis of their durability, the Compaq would appear to be slightly ahead of the Acer in this regard.

4.9 Conclusions

Given that the tablet functions were essential to have in the Paperless Classroom because they allow students to take notes just as they did on paper, there was never really a question as to whether to use tablets or laptops. However, in order to make the argument that tablets were a financially viable means of replacing paper, it was necessary to compare them side by side with their closest competitors, laptops. While laptops offer a number of advantages including larger screens and lower cost, the disparity between laptops and tablets starts to go away once a comparison of laptops and tablets of similar size and weight is performed. Since portability is crucial if students are to be expected to bring tablets with them to class every day, comparing larger tablets to larger laptops was not considered a worthwhile exercise. In the end, tablets are generally somewhat more expensive than comparable laptops, but the added expense is reasonable and necessary if students are to continue taking notes and doing work in the manner made possible by paper.

Chapter 5

Implementation

This chapter will discuss all of the details that had to be considered when formulating a complete plan for implementing the Paperless Classroom. At a high level, the major implementation decision we faced was how the Paperless Classroom would work in the first place. The decision to use Tablet PCs because of their unique ability to replace paper was already in place, but the actual specifics regarding how students would use tablets required some planning. A number of factors had to be considered, including

1. Total cost of the project and how to allocate available funds
2. The related question as to who pays for the tablets in the first place (i.e. MIT or the students themselves)
3. What loan contract to use assuming MIT was to purchase the tablets
4. How to handle conversion of course materials to digital form
5. Additional personnel requirements, e.g. for tablet setup and maintenance
6. Impact on existing teaching staff
7. The content delivery system (that is, how course materials would be distributed)
8. Which tablet models to use

9. Which software to use
10. How students would backup their data
11. How to prepare for the inevitable need for replacement tablets, batteries, styli, and hard drives
12. Perhaps of greatest importance—how to measure the success of the Paperless Classroom

I will now describe our choices in each of these areas, providing reasonable alternatives where appropriate.

The subject of financing the Paperless Classroom was listed first because it is arguably the limiting factor for the entire project. If the cost cannot be kept to a realistic level, then the project will never receive funding. However, a final description of the approximate cost of the Paperless Classroom will be saved until the end so that we can tally costs for each of the items that follow.

5.1 Tablet Purchasing

The question as to who is expected to purchase tablets, the student or the educational institution is a huge and troubling one. The tablets themselves are almost certainly the single largest cost and one way or another someone has to cover this cost. Since the initial stages of the Paperless Classroom were to be somewhat experimental and of limited scale, there really wasn't any way to require students to purchase their own tablets. Thus project funds would have to cover this cost. An option for the future, however, provided that the Paperless Classroom becomes endorsed at a higher level within the university, is to require students to purchase their tablets upon entry to the university, supporting those with special financial needs with subsidies as necessary.

5.2 Tablet Loans

Since we did have to purchase tablets and loan them to students, some system had to be in place which placed some degree of responsibility on the student for care of the tablet. If a student lost or damaged a tablet, the project could not be expected to take full financial responsibility. Our intention was to use the library system to check tablets out to students for the duration of the semester. However, this system was not yet in place when our project began, so we did in fact loan the tablets to students without establishing any formal agreement with them. However, we had an oral agreement with the students which stated that we could give them an incomplete until the tablet was returned. In fact, this was necessary in only one case, and we had no difficulty getting that tablet, and all the others, returned to us. However, a written agreement would have made the most sense in terms of protecting the project from unnecessary loss of tablets at the fault of the borrowing students. In fact, one student did end up losing a tablet (via a highly avoidable theft). Fortunately, part of the cost was covered by an MIT insurance policy and we did not attempt to recoup the remaining amount from the student in question.

5.3 Conversion of Materials

Since the tablets were to replace paper, we needed a means of giving students via the tablets what we normally give them via paper. In the case of 9.01 and 9.14, paper given to the students includes printed versions of the PowerPoint slides used in each lecture, various readings students must do to supplement lecture, study questions students must answer before lecture, official course textbooks (one or two), as well as weekly quizzes, one midterm, and one final. The bulk of these handouts consisted of the daily lecture slides and the supplemental readings.

In the case of the PowerPoint slides, the solution was relatively simple: since the slides were already in an electronic format, we used a feature built into every tablet running Tablet XP. It allows the conversion of any printable file into the Windows

Journal format by printing the desired file and choosing *Journal Writer* as the printer. Instead of printing on an actual printer, the file is printed to another file, in this case a file in the Journal format. Once lecture slides were in the Journal format, students could read and annotate the lecture slides using Windows Journal on their tablets just as they had done with paper versions of the lecture slides.

Many of the remaining handouts such as supplementary readings and study questions had already been converted to the PDF format, so additional conversion was only necessary if we wanted students to be able to annotate the PDFs. Since it was not as important for students to annotate these handouts, we opted not to convert them all to the Journal format. Students would still be able to read the PDFs on their tablets using Acrobat Reader, and since we had purchased the full version of Acrobat, students would also be able to annotate these handouts using the annotation feature which is only present in the full version of Acrobat. It is worth noting, however, that the annotation features in Windows Journal are far superior to those in Acrobat[1] so we relied upon the fact that students who had a serious interest in annotating a PDF document would be able to do so by converting the PDF to the Journal format themselves, using the aforementioned method. One other benefit of leaving files in the PDF format was that it maintained backwards-compatibility with students that did not have tablets, since the PDF format is far more standard than the Windows Journal format. In fact, we still kept and made available PDF versions of all the files we converted to the Journal format.

The textbooks were another story because electronic versions of the course texts were not available. One major dilemma the Paperless Classroom ultimately has to face is the issue of copyrights on the various course materials—not only do copyrights limit the extent to which electronic versions of documents are available, they limit the extent to which the instructor is allowed to distribute material to students. The subject of copyright is far too extensive to go into here, but it is something each implementer of the Paperless Classroom should investigate. This is obviously made

[1]This is true both of Acrobat 5 which is what we had when we started the project, and Acrobat 6, which we have since obtained, but is only slightly better than Acrobat 5 in its annotation capabilities.

much simpler when the instructor creates his own material and therefore can freely distribute it to students.

The final source of paper normally distributed to students in 9.01 and 9.14 is in the form of quizzes and exams. Although there are significant benefits to using tablet-based testing instead of paper-based testing, we decided that testing had too great an impact on students' lives to include it in our first round of experimentation. Thus, during the course of our Paperless Classroom experiment, all graded in-class evaluations were done non-electronically. Homework and papers, on the other hand, were graded and students were of course free to use their tablets for either of these. In fact, a few students chose to submit homework or papers from their tablets as e-mail attachments to the teaching staff.

5.4 Personnel Requirements

Inevitably, additional personnel would be required to perform the host of tasks associated with creating the Paperless Classroom. In our case, we were starting from scratch, so the tasks not only included the actual maintenance of the Paperless Classroom, but all of the planning and research that preceded it. These tasks included contacting tablet manufacturers to receive demonstrations and negotiate pricing, purchasing tablets and any required software, setting up the tablets for the students to use (installing any necessary software as well as Microsoft security patches), demonstrating tablet functionality to students, requesting volunteers for tablets, training tablet users on tablet functions, attending class daily to assist tablet users with software and hardware issues, collecting tablets at the end of the semester and preparing them for the next user. In our project, a single support person was hired, but a full implementation of the Paperless Classroom would benefit from the efficiency of a centralized, institution-wide, computer support service.

5.5 Impact on Teaching Staff

As stated earlier, creating and maintaining the Paperless Classroom did take some effort, and while officially this responsibility was mine, there were unavoidably some moments when the professor for 9.01/9.14 had to make special accommodations because of the tablets. One peculiar fact about our particular situation is that the professor revises his lecture slides every year and usually does so immediately before class, often producing the final version of the lecture slides only moments before class begins. What this meant for the Paperless Classroom was that he would have to change his habits somewhat so that he could prepare the lecture slides in time to give them to the tablet users (by means about to be discussed). The slides also had to be converted to the Journal format, and rather than having each individual student convert his or her own slides, we decided to do it for them so it only had to be done once. Since the professor was the only person who had a current version of the lecture slides before lecture, it became his responsibility to convert and distribute the lecture slides to the tablet users. This was not a problem as the professor did not mind this small added responsibility, but it is nonetheless something for the implementer of the Paperless Classroom to consider. Besides that small change, there was very little impact on the teaching staff. Since there were still many students without tablets, we had to continue distributing paper in 9.01 and 9.14, but in a full implementation of the Paperless Classroom, it would not be necessary to do so, resulting in significant benefits for both the professor and the TAs—in our case, this would mean that:

- The professor would no longer have to print out a copy of his slides prior to lecture to give to the TAs for photocopying.
- The TAs would no longer have to be sure to get the printed lecture slides from the professor prior to lecture.
- The TAs would no longer have to produce a copy of the slides for each student in the class (as many as 80 students per class).
- The TAs would no longer have to leave extra printed copies of the lecture slides

outside the professor's office for those students who had missed lecture and wanted to pick up the slides later.

The result would be that the professor and the TAs would spend less time working on the above tasks, freeing up more time for other activities such as meeting with students or creating better course materials.

5.6 Content Delivery System

Given that the professor will be converting lecture slides into Journal format on his tablet[2], and given that students will have tablets capable of reading the Journal format, there is still the question as to how the lecture slides will get from the professor's tablet to the students' tablets. In our case, some existing resources at MIT would turn out to be most useful, namely a web-based course content delivery system called *Stellar* and an extensive wireless network. Each will now be described in more detail.

5.6.1 Stellar

The *Stellar System*, generally simply referred to as *Stellar*, is a system that has been in place at MIT since the Fall 2001 term. It consists of a set of web servers that provide an intuitive and simple user interface which simultaneously allows instructors to post materials of almost any sort (e.g. PDFs, Word documents, audio files, graphics, etc) and allows students to download those materials. There are also some special features such as discussion boards, but the primary function is to help instructors organize and deliver content to students. A student accessing material on Stellar would first visit the URL http://stellar.mit.edu and would click *Find a Stellar class website*, then choose the department the class belongs to from a list of departments, then choose the specific course within that department. After selecting the course, the student

[2]It is possible to print files to the Journal Format using a non-tablet machine running Windows XP by installing the Windows Journal reader application available for free download on Microsoft's web site.

would be able to access the various materials uploaded to the Stellar site by that course's instructor using an interface like the one shown in figure B-7.

An important point is that Stellar does not simply provide a list of links to customized course web sites—it provides the skeleton of each course web site as well, relieving the course instructors of the responsibility of creating their own web sites. All the instructor has to do is upload content to Stellar and the material is automatically integrated into the course web page. A valuable consequence of this design is that all of the course web sites on Stellar are basically identical in terms of their structure and appearance, and differ only in terms of the actual links to material in each section of the web site.

Since Stellar was already in place at MIT and was, in fact, already being used for 9.01 and 9.14, it provided a simple solution to our distribution problem—the professor would distribute electronic handouts by posting them to Stellar from his tablet, and students would then access Stellar to download those handouts.

Fair Use Copyright

Directly tied to the notion of Stellar is the notion of *fair use copyright.* The Stellar system complies with fair use copyright by controlling who has access to materials—material only licensed for use by MIT students and faculty can be restricted to those parties, thereby preventing unauthorized parties from accessing the material. Without the ability to distribute materials under fair use copyright, Stellar would be only a fraction as useful as it is because no copyrighted material could ever be posted to the site. That, in turn, would dramatically reduce the amount of and variety of material accessible via Stellar.

5.6.2 Wireless Network

Even if Stellar hadn't existed, it would have made sense to distribute handouts via a web page, ftp site, or other means that allowed students to be responsible for their own download of material. One imaginable alternative would be to distribute electronic handouts before class using some portable storage medium such as USB pen drives. However, this approach is less elegant and requires more effort as the number of students increases. For all intents and purposes, a network-based distribution method scales nicely even when the number of students becomes large and does not require the purchase of additional distribution equipment, e.g. pen drives.

Given that students are to download handouts via network, the only question that remains is what type of network they should use to do it. Once again, an existing bit of infrastructure at MIT would turn out to be useful—in this case, the already large and rapidly growing wireless network. When we were starting work on the Paperless Classroom, MIT already had wireless access points in the majority of classrooms and a number of public spaces. Fortunately, the classroom to be used for our test subjects 9.01 and 9.14 was among the rooms with access points, which made things much simpler because students with tablets could download lecture slides and other handouts just prior to lecture in the very room where class was to be held. Had the wireless network not been available, the next best solution could only have been to post lectures to Stellar at least a day in advance so students could download them using the wired ethernet ports present in their dorm rooms. Another alternative would have been to create a peer-to-peer wireless network in the lecture hall before the beginning of class, but this approach might not have scaled well to large numbers of students and in any case would have required extra effort. Additionally, it would depend on the reliability of the host machine which is not as stable and dependable as a dedicated wireless access point.

5.7 Tablet Selection

The topic of how we chose specific tablet models will be explored in some depth in Chapter 6.

5.8 Software Selection

While selecting the right set of software to provide to students is important, the fact that files of virtually any format can be converted to the Journal format guarantees that students can use the tablets in their intended role as paper replacement devices without any additional software. However, since the tablets are full-fledged computers in their own right, it is only reasonable to expect that students will want to use them as such. What follows is a list of software we decided to install on students' tablets:

- Adobe Acrobat Full Version—Allows annotation of PDFs without prior conversion to the Journal format. Not required, but helpful and the software is quite inexpensive for volume educational purchases
- Microsoft Office—Overwhelmingly the most popular office tool for Windows machines. Students are accustomed to using this software and expect to have it. (Software usage data for college students supports this.[37])
- VirusScan—A virus scanner is essential because students will depend on their tablets on a daily basis and can't afford the downtime associated with a tablet that is infected and may need reinstallation.
- Critical Windows Security Patches—Totally free and essential in order to reduce the chances that a student will experience tablet downtime due to compromise via the network. In general, tablets should be kept quite secure against network intrusion because compromised machines can require reinstallation of the OS and may result in lost data.
- FTP Client—Inexpensive or free, and a useful tool which allows students to back up their data to their personal space in afs (a distributed networked filesystem that is backed up routinely). All MIT students are allocated 500 MB of space, making FTP an effective backup method.
- Telnet Client—Inexpensive or free, allows students to access their mail and use UNIX-based utilities from their tablets.

- Opera Web Browser—Although Tablet XP comes pre-loaded with the Internet Explorer web browser, another browser called *Opera* offers some nice features for tablet users. For example, when downloading a file from the internet, Opera immediately begins the download without waiting for the user to specify a destination on the hard drive for the file. Since students in our Paperless Classroom often download files right before class, this little optimization is helpful. Also, Opera offers other nice features such as a built-in popup killer.
- MS Windows Journal—As a reminder, Windows Journal is perhaps the most important application because it is what allows students to take notes in the first place. Fortunately, this nice tool is built into Tablet XP.

There are a number of other applications we could have used, but since the majority of what students needed to do was covered by the software above, keeping costs down was considered a high priority. Applications specifically designed for tablets such as Franklin Covey's *Tablet Planner*, while neat and perhaps useful, were clearly outside the realm of what students needed or expected.

5.9 Backup

The issue of backup is important because students in the Paperless Classroom would have all of their notes and presumably at least some of their other coursework on the tablets. Should a tablet fail for hardware or software reasons, it could spell catastrophe for the student without a backup of their tablet. Thus, we took this issue very seriously and sought a backup method that made it as easy as possible for students to back up their data so that they would perform the backup frequently. Our policy was to make it clear to students that they were responsible for performing their own backup, but to do as much as possible to encourage this backup. Performing the backup for students was out of the question because it would have required too much time on both the part of our staff and on the part of the students because it would require them to bring us their tablets regularly.

One factor which complicated the issue of backup was the fact that unlike most desktop machines on campus, tablets are not necessarily connected to a network around the clock. Thus, depending on an automated backup service was not terribly feasible. Therefore, students would have to manually intervene and perform the backup operation as often as they deemed necessary. During the first semester, we used a backup service, one which had a monthly fee per tablet, and still required students to manually initiate the backup procedure, though the actual backup process (i.e. the transfer of files from the tablet to the backup server) ran on its own after being started. This service was ultimately a bit too complicated and as a result not everyone used it. Thus in the following term, we took advantage of the fact that all MIT students had 500 MB of their own space in afs which they could access via FTP. Since 500 MB was more than enough to accommodate all of a students notes for an entire semester, this simple and free backup method seemed to make the most sense.

Although the FTP option works well and is free, there is another option worth considering. All students could be given a USB pen drive, at least 128 MB in capacity, which would allow them to directly back up their notes and other work-related files. This only started to sound like a good idea in retrospect, after having noticed how incredibly useful the USB pen drive was in the Paperless Classroom in terms of its ability to perform quick data transfers between tablets (most of which do not have any built-in removable storage device such as a CD-ROM or floppy drive). The disadvantage, of course, is cost (details in section 5.12).

5.10 Hardware Replacement

Inevitably, some of the students would have hardware-related problems with the tablets, be it damage due to neglect, a manufacturing flaw, or loss of some piece of hardware, e.g. a stylus or battery. We needed a policy in place that enabled us to quickly replace pieces of tablets or entire tablets so that students who depended on having a tablet because it was integrated into their academic life would not suffer longer than necessary. At the same time, more spare parts or tablets sitting on the shelves meant higher cost and fewer tablets in the hands of students. We decided to have two spare batteries on hand at all times. the professor brought these to lecture each day as they were quite small and he had to bring his tablet anyway. That way, students who had forgotten to charge their battery the night before would still be able to take notes that day. We also decided to have at least two spare styli for type of tablet in use, although one type of tablet, made by Acer, came with three styli from the factory, so no spare styli had to be purchased for the Acer tablets. We decided not to have any spare hard drives on hand because they were significantly more expensive than the styli and less frequently needed than spare batteries. As styli, batteries, and hard drives were the only user-replaceable tablet parts, the only remaining question was whether to have any spare tablets. We decided that since we needed one tablet for demonstrations and short term loans, that would be our emergency spare tablet. Keeping extra completely unused tablets on hand simply seemed too wasteful. As it turned out, turnaround time for tablets in need of factory repair was generally quite good, so our decision to use the demo tablet as the spare student tablet worked out well.

5.11 Assessment Methods

The goal of the Paperless Classroom project was not only to create a classroom devoid of paper, but to formally measure the impact of removal of paper on students. A thorough description of our assessment methods and the results of our assessment are given in Chapter 7.

5.12 Finance

Although a rigorous examination of the net cost of implementing the Paperless Classroom is a subject unto itself, I will briefly and informally provide a rough estimate of the costs involved. I will perform the cost analysis on a per-student basis, keeping the fixed costs such as the digitization of material separate. Depending on the size of the class or classes being made paperless, the largest cost will either be tablet hardware or support personnel. In the case of extremely small classes such as seminars, it may be possible for the teaching staff to take on all responsibilities of support personnel, but for even medium-sized classes of, say, 25 students, the majority of instructors will find this a daunting task given their other responsibilities. Fortunately, a properly planned implementation will scale well to large numbers of students in terms of efficiency of use of support personnel.

In any case, new Tablet PCs generally cost between \$1400 and \$2000, and it is not unreasonable to assume that volume purchasing and educational discounts would result in an average tablet cost of \$1700 for a paperless classroom project. In our case, in addition to negotiating prices around \$1700 per tablet, we were fortunate in that Compaq was kind enough to donate a number of tablets for our use in the Paperless Classroom. Nonetheless, we paid close to full price for the majority of the tablets we used.

This assumes that the institution must pay for the tablets. In a university-wide or department-wide implementation of the Paperless Classroom, it might be feasible to require all incoming students to purchase a tablet, those financially incapable of doing so receiving a school-owned tablet on loan instead. The benefit of this approach is that it virtually eliminates the single greatest cost seen by the institution, and while it does pass this cost on to the student, the fact that the majority of students purchase either laptops or desktops makes it clear that requiring students to buy tablets would, in most cases, not mean requiring students to incur an additional \$1700 expense. Instead, it would require students to incur the additional cost of a tablet beyond what they would have spent on a laptop or desktop.[3]

The specific tablet models being used do affect the cost, though only to a limited extent—the only way to drive the cost below \$1400 per tablet is to purchase used or refurbished tablets. Factory refurbished Compaq tablets, for example, can be had for as little as \$1000. For those willing to be one generation behind in terms of

[3]The assumption being that tablets cost slightly more than similarly equipped laptops and significantly more than similarly equipped desktops. In any case, the \$1700 required to purchase a tablet is well within the price range of laptops but falls within the upper-price range for desktops.

hardware, refurbished tablets may be the answer to budgetary problems. However, it is important to keep in mind that, all things being equal, a refurbished tablet may not last quite as long as a new one. Since all of our tablets were new, I have no personal experience to report regarding refurbished tablets. A related question is which options to purchase on tablets. Basically every tablet running Tablet XP should ship with at least 256 MB or ram, any less is insufficient for use with Tablet XP and should definitely be upgraded. Upgrading machines to 512 MB might even be a good idea since, in our casual observations, some students keep a number of different Journal files containing their various notes open simultaneously. Though most tablets ship with a case, those without cases definitely need one if the longevity of the tablet is at all a concern. Generally speaking, however, it is still safe to assume about $1700 per tablet when all is said and done.

The conversion of course materials carries an expense that varies depending on the existing state of the course materials. If none of the materials are in digital form then the option is either to create brand new digital materials or convert old materials to digital form. If the amount of material is large enough, then the conversion process will likely have to be sent to a document conversion service which, in the case of MIT, charges about $1 to scan each page of a document. Fortunately, this cost is fixed and does not increase as the number of students increases. And since digitization of materials carries its own host of benefits whether or not the materials are to be used in the Paperless Classroom, digitization is an important and worthwhile investment in any course. Assuming 1000 pages of material require digitization, the total cost would be $1000, which is reasonable when considering the benefits it carries.

After the expense of buying tablets, personnel costs are typically the second highest expense in the Paperless Classroom. Personnel costs will vary from institution to institution and will depend more on the scale of the operation than anything else. A large-scale, centralized operation which handles the setup and maintenance of the tablets would be the most cost effective approach.

In our case, we made use of existing infrastructure at MIT in creating our content delivery system. Had we not had Stellar or a wireless network, our next best options (described in that section) would still have been cost-free. Although one can think of scenarios in which content distribution would carry an expense, the cost-free options basically only require students to have network access of some sort, which is becoming more and more common at educational institutions nowadays. Strictly speaking, the increase in network traffic due to network-based access to course materials will show up as a cost, but one could reasonably argue that total network utilization due to students downloading handouts would be dwarfed by other, less relevant downloads and network traffic.

Software can be either a large expense or no expense, depending on what software is deemed necessary and what institutional site-licenses exist ahead of time. In our case, we paid about \$25 per tablet for a copy of Adobe Acrobat Professional, and about \$50 per tablet for Office 2000 (Office XP was more expensive and deemed not worth it despite some special features for tablets). The Opera web browser is shareware and can be registered if the user wishes to eliminate the on-screen advertising. To cut costs, we opted to leave Opera in unregistered mode because students could get by without the registered version. The remaining software was either free or site-licensed at MIT already, but those without site licenses could expect to pay around \$25 for each of the utilities such as VirusScan, FTP client, Telnet client, etc. Thus, a rough estimate for software costs is \$100 per tablet, though a project on an extremely tight budget could certainly survive without any of this software and reduce the cost to \$0 per tablet.

The various backup options all carry different costs. The backup service we initially used required special software, which fortunately was site-licensed, as well as a \$5 monthly fee per tablet, i.e. \$15 per tablet per semester. This small cost adds up quickly when taken across all tablets, thus the free alternative, FTP-based backup, became more and more attractive. If the FTP client must be purchased (i.e. is not site-licensed), then it would cost roughly \$25 per tablet, but it is a one-time cost and pays for itself by the second semester. The third option, providing each student with USB pen drives, carries a significant one-time cost of between roughly \$40 and \$80 per tablet for 128 MB and 256 MB pen drives respectively.[4] However, this backup method carries the significant side-benefit of providing every student with a means of transferring data between the tablet and any other USB-equipped computer, including another tablet (e.g. belonging to an instructor or another student). This capability can be especially helpful, for example, at the beginning of class if a student needs the electronic lecture notes and has trouble accessing the wireless network.

Replacement equipment costs vary, of course, depending on the rate of equipment failure and the type of warranty included with or purchased with the tablets. In terms of replacement equipment that must be kept on hand in anticipation of equipment loss or failure, we decided to keep one or two spare styli for each tablet model being used, as well as one or two spare batteries. Since one of the tablet models (the Acer) included spare styli, only one type of spare styli had to be purchased. Those styli cost \$50 apiece, with spare batteries for both models costing about \$100 apiece. We did not keep spare hard drives on hand since they can be purchased locally at a cost of around \$150 apiece. Thus, at any given moment, we had as much as \$500 of spare equipment on hand. We did not keep spare tablets and instead used our demonstration tablet as the spare. However, once equipment begins to fail outside of its warranty period, the costs can be considerable. Since our tablets are still in their relative youth, equipment failure has been relatively rare and what little has failed has been covered under warranty. Only time will tell what the costs associated with tablet repair will be in the long term. Needless to say, at some point it will become more economical to replace a tablet than to repair it. Since the tablets are being loaned to students, they see a variety of levels of care, but ultimately tablets appeared to be treated, at least by some students, with less care than they would have shown their own machine. This is another reason why moving to a system in which students purchase their own tablets would be beneficial. A reasonable guess at the lifespan of a tablet under continual loan to a different student each semester is about 4 years, with perhaps one minor hardware repair or replacement during that period.

[4] Typical USB pen drive pricing can be seen at http://www.supermediastore.com/256mbpendrive.html

Thus we have roughly $1000 for digitization of materials per course, that being the only one-time cost for each course. The tablet-variable costs are $1700 for the actual tablet, $100 for software, and $50 for backup (assuming USB pen drives as a backup method), a total of $1850 in initial cost per tablet. There will also be a maintenance cost (for software and hardware) over the life of each tablet, but this figure is difficult to estimate, though it clearly depends on whether the students or the institution own the tablets.

The cost for digitization of materials is minimal compared to the benefits digital materials provide. Even in the absence of tablets, simply having the ability to post files on the internet for students to access at their convenience is worth the investment. The tablets cost $1850 plus some unknown (but probably reasonable) maintenance cost. Assuming paper copying costs of 3 cents per page, and using the 1400 page per semester estimate given in section 4.3, the total copying cost for one student for one semester is $42. However, when considering that students with tablets receive all their handouts in color, it is worth at least considering what it would cost to provide color copies of all their material. Assuming that only one in four pages warrant color copying, there would be 350 color pages at $1 per page, and 1050 black-and-white pages, at 3 cents a piece, which comes to a total of $381.50. Ignoring maintenance costs for a moment, this means a tablet would have to last about 5 semesters to be worth the investment, given the (numerous) assumptions that have been made. As was mentioned in section 3.4, a study of laptops used in a library setting [13] showed laptop lifetimes of about two years. However, these were extreme conditions and the laptops were under continual use and were used by a variety of people, only one of which would have had to have been careless in order for the laptop to be damaged, perhaps in a way not apparent to the library personnel. In the Paperless Classroom, a tablet lasting five semesters would see, at most, five distinct users during its required five semester lifetime. A model in which students own their own tablets would likely result in even higher lifetime expectancies for the tablets. What makes cost analysis of the Paperless Classroom difficult in the end is the difficulty in weighing money on one side of the equation against potential academic or motivational gains on the other side. The question boils down to this: what is learning worth?

Chapter 6

Tablet Selection

In order to make the Paperless Classroom as successful as possible, it was necessary to review all of the available Tablet PCs to determine which models were most appropriate for our purposes. In actuality, almost all tablets currently on the market would have been able to perform the functions required of them. However, the decision as to which tablets to use was still important because if students did not enjoy using their tablets, it was doubtful that they would be enthusiastic about using them in place of paper. Likewise, finding a tablet that the students instantly enjoyed was sure to increase our success. This chapter will discuss the criteria we used in selecting a tablet from the set of over 20 tablet models we considered and tested.

6.1 The Ideal Tablet

There are a number of things we should look for in a tablet to ensure that it will be as beneficial to the student as possible. The ideal tablet:

- Has a practical form factor—it comfortably allows desired modes of use (e.g. use in "tablet mode" or "laptop mode").
- Is fast and user friendly—it maximizes a student's ability to efficiently store and retrieve information. Excessively slow tablets will frustrate students and waste their time, and time is especially precious at the beginning of lecture

when students must boot their tablets and download lecture slides before the lecture begins.

- Is lightweight—the student is not discouraged from bringing it everywhere. The more often a student has his tablet, the more chances he will have to use it. Furthermore, portability gives students a more extensive set of options regarding where and with whom students do their work and this added flexibility could have a measurable impact on student performance and morale.

- Has a long battery life—if the student does bring it everywhere, it won't run out of charge. Although the tablets have fairly portable power adapters, there are places and occasions where working next to a power outlet is not an option—this includes many classrooms at MIT which only have power outlets scattered along their periphery. A tablet that drains its battery too quickly will frustrate students and, in the worst case, actually prevent them from studying or taking notes, thus a long battery life is indeed important.

- Has a nice stylus—the act of writing is natural and predictable. This is actually a function of the stylus, the digitizer, and the tablet screen itself. The care with which the digitizer and stylus are designed will affect the accuracy and consistency of the act of writing as well as the degree to which manual calibration of the digitizer is required. The screen will affect the tactile experience of writing and all of these factors combined will determine whether or not a student finds himself wishing he could go back to paper because of undesired output or discomforting tactile response from writing.

- Is inexpensive—practical concerns demand this. Given that a tablet meets minimum requirements for each of the above, keeping the cost to a minimum by avoiding unnecessary features or overpriced tablets is the next most important concern. Cutting cost to the extent that it produces a major shortcoming in any of the above areas is not an option because it will inevitably result in a negative experience for the student.

6.2 The Actual Tablets

Over the course of the early months of our project, from May to November 2002, we reviewed a total of 23 different tablet models, testing the majority of them in person, and studying the specifications sheet of the remainder. By far the most impressive and full-featured of these was the generation of tablets, released jointly with the Tablet XP operating system on November 7, 2002,[1] but since they were not yet available to us at the time, we proceeded to test the tablets that were available. These included a number of military specification tablets capable of feats such as being thrown from a moving truck during operation, and the like. One particularly enjoyable tablet was basically a laptop with a touchscreen but stood out from the crowd because of backlit keys and full waterproofing, making it the only tablet/laptop I've ever seen that could be used underwater in complete darkness.

We also tested a number of tablets intended for civilian use, ranging from the cute but incredibly lethargic ProGear 1050 SE made by SonicBlue to fairly nice and affordable (about $1800) ViewSonic VP1000 which suffered from the so-called palm problem (see section 4.2.1) because of its (otherwise nice) large screen and touch-based digitizer. We also tested the Fujitsu Stylistic 3500 which used a touchscreen but had special palm-rejection technology, making it the most suitable choice of all tablets available prior to the new generation of tablets running Tablet XP. Unfortunately, the price was prohibitively high—just over $3000. The other tablet of interest from this pre-Tablet XP era was the Hammerhead H2 military grade tablet which resembled the new breed of tablets more closely than any other because it used an active digitizer, and was in fact the first tablet I tried that used this more advanced digitizer technology. Upon trying it, I was instantly convinced that the new breed of tablets, all of which were slated to use an active digitizer, was worth waiting for—the bad news was that we had to wait until November 7, 2002, which was two thirds of the way through the first semester of our paperless classroom.

The new breed of tablets released on that date represented a major improvement.

[1]With the exception of the Acer tablet which was made available prior to that date against Microsoft's wishes

All tablets before them were either totally inadequate/inappropriate, too expensive, or in the case of the ViewSonic VP1000, was reasonably priced but not fully adequate as a writing device. These new tablets were excellent writing devices (thanks largely to Windows Journal) and were reasonably priced. Although these new tablets were manufactured by a total of 6 companies—Acer, Compaq/HP, Fujitsu, Motion Computing (under the Gateway label), Toshiba, and ViewSonic (NEC and Electrovaya have since joined in as well). The Fujitsu, Motion Computing, and ViewSonic tablets were pure slates, the Acer and Toshiba were convertibles (i.e. had a built-in keyboard and converted in-between a tablet and a laptop), and the Compaq was similar to the convertibles but had a removable keyboard, allowing it to become a pure slate.

Although we considered each of these manufacturer's tablets, we focused on the Acer and Compaq tablets because of the appeal of their designs and our ease in forming relationships with the manufacturers as part of this project. Among the convertibles, we considered the Acer preferable to the Toshiba because it weighed only 3 pounds, the Toshiba a relatively heavy 4.4 pounds. The Compaq had a unique hybrid design that was compelling and made it an immediate candidate. The fact that the Acer and Compaq functioned well as tablets and provided a keyboard lessened our interest in pure slates, however, for the sake of comparison, I will also add the ViewSonic (model VP1100) to the mix, allowing us to compare one tablet from each of the three categories—pure slate, convertible, and hybrid.

Thus our three final candidates were the Acer TravelMate 100, Compaq/HP TC1000, and ViewSonic VP1100. What follows is a comparison of each of these using our criteria described in section 6.1.

- Has a practical form factor—each of our three tablets under consideration has a different form factor. The Compaq is in a sense the most versatile because it is capable of behaving exactly like a pure slate but allows for graceful attachment of a keyboard. The Acer also has a slick means of providing a keyboard and functions slightly better as a laptop than the Compaq because of its lower center of gravity. Thus the Acer and Compaq each have their advantages and either may be preferable depending on the situation and on the user. The

ViewSonic would only be desirable for someone who made relatively scant use of the keyboard, but it was decided that that was not a description that reminded us of MIT students. Furthermore, a keyboard attached to the ViewSonic, or any of the "pure slate" tablets would not be tightly connected to the tablet—there would essentially be two pieces of equipment to handle. This would be extremely clumsy, arguably impossible, on any of the standard flipdesks in classrooms.

- Is fast and user friendly—In terms of CPU used, the Acer and ViewSonic were almost identical, having an 800 and 866 MHz Low Voltage Pentium III respectively. The Compaq took a different approach, using a 1 GHz Transmeta TM5800 (a.k.a. *Crusoe*) CPU which I found, using benchmark software, to perform as well as a 1 GHz Pentium III in terms of raw speed, but which subjectively lagged behind the other two competitors. The reason for this discrepancy was undoubtedly due to the fact that the Transmeta CPU translates Intel CPU instructions into its native instructions and also caches translated instructions. This means that when the cache is performing well, the CPU will cruise along (so to speak) behaving like a 1 GHz Pentium III. But when cache performance is low (i.e. the cache miss rate is high), the machine will be considerably slower. This evidences itself as a small but irritating lag associated with the majority of operations performed while using the Compaq. Upgrading the RAM in the Compaq to 768 MB helped, but ultimately the machine still felt disappointingly slow at times.[2] Thus, the Acer and ViewSonic jointly win the speed contest.

- Is lightweight—The Acer, Compaq, and ViewSonic weigh 3.2, 3.04, and 3.4 pounds respectively, all including batteries. The Compaq weight given does not include its detachable keyboard—with keyboard, the Compaq weighs 4.0 pounds. Thus the weights are comparable (though the Compaq has a slight lead), assuming the Compaq is without its keyboard. However, considering the weights with keyboard, the Acer is significantly lighter than the Compaq (and

[2]Compaq has clearly paid attention to user feedback and changed the CPU in its new model, the TC1100, providing the option of either an 800 MHz Celeron or a 1 GHz Centrino.

the ViewSonic is not applicable in this comparison since it has no keyboard). If a winner had to be picked, it would have to be the Acer for being almost as light as the lightest and for having a keyboard to boot. The clear loser (though not by much) is the ViewSonic which is heavier than the Compaq (without its keyboard) and the Acer.

- Has a long battery life—Unlike the other comparisons, the exact battery life for these tablets is difficult to pin down because the life depends somewhat on how the tablet is being used. However, in my informal tests of battery life for each of these, I found the Acer and ViewSonic to be similar (as could be inferred from their using nearly identical CPUs) while the Compaq lasted at least half an hour longer, thanks no doubt to its power-saving Transmeta CPU which resulted in its being slower than the other two tablets. Thus the Compaq demonstrates the existence of a tradeoff between performance and battery life. If speed weren't an issue, this increased battery life alone might make the Compaq the winner.

- Has a nice stylus—Since each tablet being compared runs Tablet XP, and therefore Windows Journal, the software is not a variable in this comparison. The writing quality is simply a function of how well designed the stylus and digitizer are. The Compaq had the nicest tactile feel while the Acer and ViewSonic had one feature the Compaq lacked—pressure sensitivity.[3] While not essential for our purposes in the Paperless Classroom, pressure sensitivity does make writing with the tablet more natural and may actually help in cases where fine control over the heaviness of the ink must be controlled without continually making manual changes in the pen thickness. Thus each tablet has an advantage here and specifying a winner or loser is difficult.

- Is inexpensive—The pricing of tablets depends somewhat on the number of tablets being purchased as well as the vendor being used. It also depends on whether or not a special arrangement is made with the manufacturer. In our

[3]Compaq has added pressure sensitivity to their new tablet, the TC1100.

case, we negotiated prices of $1999, $1620, and $1899 with Acer, Compaq, and ViewSonic respectively, so the Compaq was the clear price leader.

To summarize, the Compaq had the most flexible form factor allowing both "laptop mode" and pure slate usage, but the Acer had a fairly slick means of converting between these modes as well. The ViewSonic provided no graceful means of attaching a keyboard. The Acer and ViewSonic were quite speedy with the Compaq having speed as its weak point. Weights were comparable, though the ViewSonic was heaviest by a slight margin. The Compaq led the other two in battery life and the three tablets each had its own advantage in terms of writing quality. The Compaq was the price leader while the Acer was the most expensive, $100 more than the ViewSonic. Thus, in terms of elimination, the Acer and ViewSonic were comparable but the superior form factor of the Acer (and its impressive weight advantage given that even with a built-in keyboard, it was lighter than the ViewSonic) made the extra $100 for the Acer seem worthwhile. In comparing the Acer and the Compaq, both provide nice options for use of a keyboard, and the Compaq basically trades speed for battery life. Thus the better machine may be a matter of preference for battery life or speed, but given the price gap, the winner must be the Compaq. Finishing position—Compaq, Acer, then ViewSonic.

Thus it was our decision to purchase mostly Compaq tablets with the remainder consisting of Acer tablets. We thought that having two different types of tablets would be interesting in terms of learning how students react to and use the different tablets. Also, since the Acer and Compaq represented different tradeoffs in terms of performance, battery life, and form factor (means of keyboard attachment in particular), we felt that each student might each benefit from having a particular tablet.

Chapter 7

The Paperless Classroom

This chapter provides a description of our experiences and informal observations that took place over the course of the first three semesters of the Paperless Classroom—the Fall 2002, Spring 2003, and Fall 2003 terms. This chapter will also set the stage for description of the formal measurements given in chapter 8.

It will be helpful to recall that 9.01 is the course number for the introductory undergraduate Neuroscience course at MIT and that it is taught every fall with roughly 80 registered students. 9.14 is the follow-up course to 9.01 and is quite similar to 9.01 in format though it focuses more on development of the brain that does 9.01. 9.14 has a much smaller enrollment, typically 20-25 students per term. Both classes are taught by Professor Gerald Schneider with 3-4 teaching assistants for 9.01 and one teaching assistant for 9.14. Both classes meet every Monday, Wednesday, and Friday during the 13-week semester and both have regular quizzes, some homework, a single midterm, and a final exam.

7.1 Fall 2002

Preparatory work on Paperless Classroom project started in May of 2002, with preparations including testing of tablet hardware and negotiation of tablet pricing with various manufacturers as well as the securing of funds for the project. The goal was to provide tablets for as many interested 9.01 students as possible, and to do so about two weeks into the term (by which time most of the early dropouts were gone). This goal would turn out to be difficult because, as described in chapter 6, the new breed of tablets running Tablet XP would not be available until November 7 of that year (almost two thirds of the way through the semester) and tablets not running Tablet XP were either too expensive or inadequate as paper replacement devices. Nonetheless, we struggled to find ways of having a decent Paperless Classroom going by the second week of the term and our best chance was to somehow secure machines running Tablet XP prior to their release date, with hopes of becoming part of a beta test program. While we thought this would be attractive to tablet manufacturers because our findings could be given to them prior to the release of tablets to the general public, apparently the nondisclosure requirements of Tablet XP made giving pre-released tablets to a handful of students our class infeasible.[1]

Thus, regrettably, no tablets were distributed at the beginning of the semester. However, we had every reason to believe that tablets running Tablet XP would be available to us starting November 7 of that year, so we pre-ordered six tablets from Compaq so that a four-week-long experiment could be held at the end of the term. However, delays in the shipment prevented even this small experiment from happening though we did receive one Compaq TC1000 tablet for testing. In the end, we were forced to gather all of the older tablets we had on loan for testing from various manufacturers and we gave students these tablets for approximately the last week of classes prior to finals so we could at least try out our implementation and iron out the bugs before the next semester. The tablets we gave out varied significantly in quality, and consisted of two SonicBlue ProGear 1050 SE tablets, one kludgy tablet of obscure Taiwanese origin, a Viewsonic VP1000, Viewsonic VP1100, and the Compaq TC1000. Only the last two tablets ran Tablet XP, and of those that did not run Tablet XP, only the Viewsonic VP1000 was respectable in terms of its note-taking abilities. Nonetheless, we gave students every last tablet we had for the sake of testing the full range of tablet hardware. As suspected, informal observations of student satisfaction

[1]Even though, several months prior, another group at MIT was allowed to do essentially the same thing we wished to do.

with the tablets correlated almost perfectly with the quality of the machine they were given.

The students with tablets running Tablet XP were extremely pleased and successfully used Windows Journal to take notes on electronic versions of the lecture slides during the last week of classes. The student with the Viewsonic VP1000 was pleased to have a tablet and successfully took notes, but lacking Windows Journal, she had to use the full version of Adobe Acrobat 5 in order to take her notes on the lecture slides and as a result her notes were not as neat or detailed as those produced on the Tablet XP machines.[2] The remaining three students were excited to have a tablet at first, but quickly came to the same conclusion we did, namely that their tablets were too slow to be at all useful in taking notes. Thus the students' reactions confirmed our conclusions regarding which tablet hardware to use—tablets running Tablet XP were, without a doubt, the way to go, and the Paperless Classroom would have to wait until we actually had some.

One other interesting development during this first semester of the Paperless Classroom was that, at my recommendation, the professor started using Windows Journal on the Compaq TC1000 tablet (the one we were given for testing purposes) in place of the blackboard. While the professor already used PowerPoint slides for most of his lecture, he would occasionally need to draw a diagram on the blackboard and these diagrams were generally quite difficult to see. Projecting his PowerPoint presentation from the tablet (instead of the laptop he previously used) allowed him to efficiently switch between the PowerPoint presentation and Windows Journal as needed. The tablet was used in this fashion for almost a month (up until it was given to a student during our test in the last week of classes) and during that time there were only difficulties on two occasions—both problems were related to the tablet's connection to the overhead projector.

We also distributed an informal survey on the last day of class asking four questions

[2]In fact, the absence of an eraser tool in Acrobat 5 was an added handicap which made it all the clearer that the annotation feature in Acrobat was added as an afterthought. While an eraser tool was added in Acrobat 6, the annotation functions are still quite primitive compared to those in Windows Journal.

about tablets (in addition to the regular course-related questions). Since the survey was fairly informal, I will report the results now instead of in chapter 8 which is concerned with the formal assessments. What follows are the four survey questions and the means and standard deviations associated with each reply ($n = 51$ in each case):

- A Tablet PC was occasionally used to create and project drawings during lecture. Was this effective (1=not effective, 5=very effective)?
  $\bar{x} = 3.6, s = 1.2$

- To the best of your knowledge, if you had had a tablet all semester, do you think it would have been helpful (1=not helpful, 5=very helpful)?
  $\bar{x} = 3.6, s = 1.2$

- How interested would you be in trying out a tablet: becoming familiar with the new software, hardware, etc (1=not interested, 5=very interested)?
  $\bar{x} = 4.0, s = 1.3$

- How large a role would you expect tablets to play in education at MIT in the near future (e.g. 5 years from now) (1=no role, 5=very significant role)?
  $\bar{x} = 3.7, s = 1.1$

The results show above average, albeit not overwhelmingly positive, responses to each of these questions, with the most positive response corresponding to student interest in becoming familiar with a tablet. Overall, the results were encouraging, particularly because some of the tablets we'd given out a week before giving this survey were not nearly as sophisticated as the tablets running Tablet XP and had the potential to reduce the interest in tablets of anyone who came into contact with them.

7.2 Spring 2003

Almost unimaginably, of the six Compaq TC1000 tablets we had ordered months prior, only three were available at the beginning of the Spring 2003 term. We asked the students in 9.14 for volunteers, and randomly selected three students from the volunteer pool and gave them each a brand new Compaq TC1000 Tablet PC. I introduced them to the tablet hardware and software, and demonstrated how they would be using the tablet instead of paper.

The process, as described in chapter 5, was for them to connect to the wireless network in the lecture hall before the beginning of class, visit the Stellar website, find the 9.14 course listing, and scroll down to the material listed under that day's date, download the Windows Journal file containing that day's lecture slides, take notes on the slides during lecture just as they would on paper, and save the file in a safe place of their choosing when lecture was over. From the very first day, these students were able to take notes in the above fashion virtually without incident.

The remaining three tablets from our original order finally arrived shortly after the midterm (mid-April 2003), along with three additional tablets, bringing the total number of tablets to nine, all Compaq TC1000 tablets. We immediately distributed these six new tablets to a randomly selected set of students from the original volunteer pool, and provided each of these students with the same instruction that had been given the first three students. They too took notes using the tablets for the remainder of the semester with little trouble to speak of. There were occasional transient problems connecting to the wireless network (the source of which we never really determined) as well as a few styli that behaved erratically and were promptly replaced by Compaq.

These occasional wireless connectivity issues prompted us to purchase two 128 MB USB pen drives, one for myself, and one for the professor, which allowed us to directly transfer the lecture notes to a student whose wireless was malfunctioning. As noted in section 5.6.2, using USB pen drives to transfer lectures to all the students is not a viable option, but if only one to two students have wireless problems then the USB pen drive is a valuable backup means of transferring the lecture. In general, spontaneous tablet-to-tablet transfers are more easily accomplished using a USB pen drive because using the wireless network for such transfers requires either the use of network shares (a security risk) or the use of an FTP server.[3]

Apart from these minor issues, informal observation indicated that the tablets performed their role as paper replacement devices exactly as expected for each of the nine students. During the course of the semester, we also asked students in the neuroanatomy class (9.14) to participate in a number of voluntary surveys and other assessment procedures. These assessment methods are described in chapter 8.

7.3 Fall 2003

As a result of our successful Spring semester using tablets, it became easier to secure funding for tablets. The result was that by the beginning of the Fall 2003 semester, we had sixteen tablets available for 9.01 students which consisted of both Acer tablets and Compaq tablets (we had only used Compaq tablets the previous term). An additional six tablets would become available just prior to the midterm (late October) and two more followed just after the midterm, and all of these, 24 tablets in all (15 Compaq and 9 Acer), were distributed to students.

Each of the students receiving a tablet was drawn randomly from a pool of volunteers, and over the course of the term additional students asked to be added to the list as their exposure with the tablets increased. (They presumably gained interest either because they had friends in the class that had tablets or simply because they observed others in the class using the tablets.) However, volunteers who volunteered first were given priority over those who volunteered later.

Each of the students receiving a tablet was also given the same introduction to the tablet hardware and software as their predecessors in 9.14, the only difference being that some students now had tablets of Acer manufacture, and thus received a

[3]The sender would FTP the files being transferred to a location on the FTP server that the recipient has access to, the recipient would then download the files from that server—a bit cumbersome.

slightly different briefing on hardware.

7.3.1 Problems Encountered

Perhaps merely because there were so many more students with tablets than in the previous term (the majority of whom had them all semester, unlike those in 9.14), there was a wider variety of problems encountered over the course of the semester. The day-to-day problems encountered per capita were, however, roughly comparable to those in the previous term. I will now discuss the various issues we encountered over the course of the Fall 2003 semester, ranging from the major to the minute.

Student Caused

Theft and Loss There was, unfortunately, one Compaq tablet stolen during this semester, bringing the total number of tablets in 9.01 down to 23 (fourteen Compaqs and nine Acers). The student whose tablet was stolen stated that she was in the MIT Student Center (a well-frequented public space with multiple floors offering services ranging from a convenience store to study areas with couches and televisions) with some of her friends and left the tablet unattended on a table for two to three minutes, and when she returned, the tablet was gone. This is, of course, only one of many possible theft scenarios but illustrates an important point—it does not take long for a highly portable, widely-useable, $1800 piece of equipment to vanish when left unattended in a public space. In this case, the theft was highly preventable, the lesson for the implementer of the Paperless Classroom being that it is inadequate to assume that all students receiving tablets have common sense regarding theft avoidance and that an explicit discussion on the topic prior to tablet distribution is warranted. Unfortunately, we were still working out a formal means of holding students responsible for the safe return of their equipment at the end of the term, so the project had to cover the cost of replacing the tablet. This also provides one argument for moving to a system in which students are required to purchase their own tablets—it is possible that students would apply a greater degree of care to their own equipment, and regardless, any theft would be the student's problem, placing the ownership of and responsibility for the tablet in the same hands.

There was only one other case of equipment theft/loss during the Fall 2003 term—a student lost the stylus for his Compaq, and we covered the $40 replacement cost for him. All remaining equipment which included the tablets themselves, the styli, power adapters, and cases, were returned in good condition at the end of the semester (though one student "inadvertently" took the tablet home over winter break despite our request that it be returned during finals week, which is just prior to winter break).

Student Nonattendance Though lack of student attendance is not a problem, *per se*, in the extreme case it constitutes a waste of resources for a project with limited funding. The purpose of the tablets was to replace paper, specifically the paper normally used to take notes in lecture. So it is frustrating to give a tablet to a student only to have it go unused. There are, however, two reasons why we cannot recall tablets from such students—first, they may be using the tablet outside of class, quite possibly in a way that helps their performance. Secondly, filtering out students who do not attend class would impose an artificial bias in the sample, quite possibly resulting in an apparent increase in the performance of tablet users assuming that nonattendance results in a grade reduction (generally the case in 9.01 and 9.14 which depend heavily on material taught in lecture).

There was, in fact, only one severe case of nonattendance, a student who attended with regularity at first and then basically vanished but continued to do some of the required coursework up until (but not including) the final exam. Ultimately, this student failed to complete the course and received a medical excuse, and he was therefore removed from our dataset (bringing the total number of tablets in the dataset down to 22—13 Compaqs and 9 Acers). The only other tablet-bearing student removed from our dataset contracted mononucleosis partway through the term and had to drop the course, her tablet going to another volunteer at that time. In fact, all students, regardless of whether they received a tablet or not, were removed from our dataset if they dropped the course or received an incomplete. All students who completed the course were included in the data analysis given in chapter 8. The majority of the remaining students with tablets attended regularly, with only one or two attending somewhat sporadically.

Tablet Nonattendance Although students who came to class on a given day almost always used their tablet, there were some occasions when they did not. Several students, when asked why they had used paper on a particular day, stated that their battery was drained. When students are originally given their tablets, they are informed that we bring spare batteries for each model tablet to each lecture, but some students claimed to have forgotten this. However, the problem, or at least the particular excuse, seemed to go away after we reminded the students that we provided spare batteries.

Students also forgot to bring their tablets on occasion. On these days the students were still able to take notes since paper handouts were still being distributed to those students without tablets. However, once the Paperless Classroom leaves the testing stage, printouts will no longer be provided, so students forgetting to bring their tablets will have to use a blank sheet of paper, unless they print out the lecture slides in advance.

In any case, students with tablets brought them the vast majority of the time, so tablet nonattendance was not considered a significant problem.

Tablet Caused

Wireless Problems Wireless networking problems were by far the single largest source of difficulty we (and students) encountered due to the tablets themselves. These problems exhibited themselves in various ways—generally students would approach me at the beginning of class stating that they were unable to connect at all. On other occasions, a student's tablet would claim to be connected to the network, but there was no actual indication of a connection. The third case we encountered was that the connection was clearly established, but the download of the lecture slides proceeded at an exceedingly slow rate. Though it was beyond our abilities to identify the exact sources of these three related issues, there were some simple solutions that worked most of the time.

We found that the quickest way to handle most problems of this sort was to disable and then enable the wireless connection.[4] It is likely that this solves problems caused by old network data such as routing tablets not being refreshed properly when the tablet is moved between wireless access points, though this is only conjecture on our part.

Another tactic is to open a command prompt and type *ipconfig /release* followed by *ipconfig /renew*. This causes the tablet to re-contact the DHCP server to receive a new dynamic IP address for the wireless network adapter. Finally, if all else fails, rebooting the tablet works virtually every time.

One possible explanation for some of our troubles with wireless is that, since we had as many as 24 students using wireless all at the same time, and since there may even have been others outside the classroom but within range of the access point (which is located within the lecture hall near the entrance), the access point may have reached its limit of 30 connections.[5] Had we had many more students with tablets, it would have been necessary to add another access point.

In any event, while problems with wireless were the single largest technical problem we encountered, they were not terribly frequent, considering the total number of students with tablets. I would estimate than, on average, that there was one wireless-related issue per lecture.

As we had done in 9.14 the previous semester, we used USB pen drives to transfer the lecture slides directly to any students whose troubles with wireless prevented them from downloading that day's lecture slides. Since students quickly learned how to perform file transfers using the pen drives, we could even just hand them a pen drive and they knew what to do with it—find a friend with a tablet and ask them to

[4]This can be accomplished by choosing *Settings* from the Start Menu, then opening *Network Connections*. Then, within the Network Connections window, right-clicking on the *Wireless Network Connection* and choosing *Disable* will disable the connection after which right-clicking on it again allows the user to select *Enable* to enable it once again.

[5]The number of simultaneous connections possible depends on the particular access point being used, but in our case, the access point can handle 30.

put the lecture on the pen drive.

Windows Security Issues Another problem we encountered with the tablets, though not one exclusive to the tablets by any means, was the barrage of critical security holes discovered in several Windows operating systems (including Tablet XP) which required us to install security patches on each of the students' tablets. We used USB pen drives to install standalone versions of the patches because some of the security holes were so severe that a machine attempting to download the patches could easily get infected before the download was complete. Again, this was not the fault of the tablets, per se, it was simply an issue that had to be dealt with and may need to be dealt with again in the future. While some students are savvy enough to handle such critical security updates on their own, many students need to be asked to perform the updates and some even need help with the update procedure, especially if the update is of the critical sort that warrants use of a USB pen drive instead of a direct download and the student in question does not have a USB pen drive or does not know where to get the standalone version of the update.

Tablet latches The only major physical problem with the tablets was related to the latch mechanisms which hold closed the hinge connecting the screen and keyboard, either with the screen facing inwards as a laptop with its screen closed down, or with the screen facing outwards, to allow operation in tablet mode. These had a tendency to break on both Compaq and Acer tablets. (Three out of fourteen Compaqs had broken latches and three out of nine Acers had broken latches.) While the broken latches do not prevent the tablets from functioning, they do serve a purpose and without them the screen and keyboard components of the tablet rattle against each other while the tablet is being transported, something that is both irritating and potentially bad for the tablet. In the case of the Acer, it also makes using the tablet in tablet mode annoying because the screen does not stay flush against the keyboard while you are writing. The Compaq, fortunately, has a detachable keyboard and it thus unaffected by the broken latch during use. The latches are covered under warranty but sending tablets in just because of a broken latch is not quite worth the effort, and certainly not worth it to the student who would be without the tablet for several days.

Conclusions

Thus in this third term of the Paperless Classroom, we discovered a healthy array of problems and probably saw our first true glimpse of what the final paperless classroom would be like. However, considering that 24 students used tablets, most of them for the entire term, the list of problems seems fairly reasonable and the experience for any given student consisted almost entirely of trouble-free operation with perhaps two or three minor issues per student per semester, an acceptable rate considering the potential benefits which consisted largely of their having a semester's worth of electronic notes.

Students' opinions regarding the experience with the tablets are, of course, even more important than my impressions of their experiences, and data concerning these opinions, among other things, will be presented in chapter 8.

Chapter 8

Assessment

8.1 Introduction

One of the primary goals of our Paperless Classroom project was not only to implement a paperless classroom, but to determine the success of that implementation along a number of dimensions. The question as to whether having tablets would improve students' performance, as measured by the preexisting grading procedures, was arguably the most important one since the primary function of the classroom is to convey knowledge and prepare students for whatever may follow (e.g. research, work in industry, etc). The assumption, of course, is that grades do a reasonable job of measuring a student's knowledge, experience, etc.

In addition to measuring the effect of tablets on grades, we gave students a number of surveys as well as a computerized test which determined their learning style in order to determine how factors such as motivations to learn, learning style, and attitudes towards technology and the courses being taught were either affected as a result of their having a tablet, or were related to students' volunteering for a tablet in the first place. All tablet users were given exit interviews and in the Fall 2003 semester they also had software installed on their tablets which provided us with information about their usage of the tablet. These assessment measures also serve to characterize the group of students as a whole which is useful in determining whether the test courses 9.01 and 9.14 in which tablets were distributed differ in any respects from university level students elsewhere. While we will not compare our students' responses to those of other university students, extreme results in any measure may serve to indicate a peculiarity of students taking 9.01 and 9.14 and potential non-applicability of our data to other student populations.

8.1.1 Three Semesters of Assessment

The assessment methods used varied over the course of the three semesters, with particularly little assessment having been done in the Fall 2002 semester of 9.01. Assessments performed over multiple semesters are pooled when appropriate to increase the sample size. Each assessment considered each student as belonging to one of three categories—students who volunteered for a tablet and received one, students who volunteered for a tablet and did not receive one, and students who did not volunteer for a tablet. Of import is the fact that students who received tablets were drawn at random from the entire volunteer pool. Thus, the volunteers without tablets can serve as an effective control against those with tablets whereas non-volunteers would not be an ideal control because they may be considered a different population—their attributes as measured by each assessment may be significantly different from those who volunteered for a tablet. For example, students who volunteer for a tablet might do so because they have lower grades and need every bit of help they can get. Thus, if tablet users have lower grades than non-volunteers, we cannot necessarily assume that the tablets did not help the students. If, however, tablet users' grades are lower than those of the volunteers who did not get tablets, then it is probably safe to conclude that the tablets were responsible for the grade drop.

While almost all analyses will treat students as belonging to these three groups, there will be occasions when it is appropriate to combine two or more of the groups, the benefit being that the resulting merged groups will have a higher sample size. For example, in a beginning-of-term survey which is given prior to the distribution of tablets, it is possible to merge all volunteers, regardless of whether they eventually receive a tablet, into a single volunteer group. Likewise, there may be occasions when a significance level is only achieved by grouping together all students without tablets, regardless of whether they volunteered for one, though I will do this sparingly because I prefer using the volunteers without tablets as basis for comparison because they constitute a control (since tablet distribution was random). Finally, I will sometimes group all students into a single class-wide group for purposes of describing the overall student opinion or score on a given measure.

Fall 2002

The assessments performed in the Fall 2002 term of 9.01 consisted of a survey called the *Learning Attitudes Questionnaire (LAQ)* and a small informal survey regarding tablets, the results of which were already given in section 7.1.

Spring 2003

The assessments used in the Spring 2003 term of 9.14 consisted of matched surveys (i.e. containing the same set of questions) offered at the beginning of the term and at the end of the term, a computerized test called the *Cognitive Styles Analysis (CSA)*, exit interviews for each of the students with tablets, as well as the same LAQ survey offered the previous term.

Fall 2003

The assessments used in the Fall 2003 term of 9.01 consisted of a survey at the end of the semester,[1] the same LAQ survey, CSA test, and exit interview given in 9.14 the previous semester, a new survey which measured students' retention of material immediately after lecture, as well as the use of software which measured the amount of time students spent using their tablets.

[1]This survey contained the same questions asked in the matched surveys the previous semester—the survey was not offered at the beginning of the term because of limitations on the numbers of surveys we could offer.

Means of Analysis

Since tablets were not distributed in the Fall 2002 term of 9.01 (except informally during the last week), the data from that semester was limited and will serve as a comparison between the volunteer and non-volunteer groups for the LAQ survey and the grade data. The LAQ, CSA, end-of-term survey, and interviews were offered in identical form for both of the two semesters in which tablets were distributed, Spring and Fall 2003. Thus these data will be considered both separately and as pooled data for purposes of analysis. The beginning-of-term survey (while identical to the end-of-term survey) was only offered in the Spring 2003 and will thus only be considered in conjunction with the end-of-term survey for that same semester in order to determine changes that took place during that semester. The survey concerning post-lecture retention of material and the software which determined students' usage rates of the tablets were only used in the Fall 2003 term and cannot be pooled with data from other semesters.

In addition to the above measures, grade data consisting of quiz grades, paper and homework grades, midterm score, final exam score, and final overall score will be considered independently for each of the semesters. The grade data cannot be pooled across semesters because the grading scale varies too much from semester to semester especially given that 9.01 and 9.14 are different courses. A final means of data analysis, performed independently for each of the two semesters in which tablets were distributed, is a cross-correlation of all data collected in an attempt to find interactions between data from within and across the various measures.

8.2 Data Analysis, Significant Findings, and Interpretation

I will now present a description of each measure, followed by the results for each semester in which the measure was performed. While I will not provide raw data, I will provide a summary of data from each measure in the form of a chart showing mean and standard deviation (by the use of error bars) as well as a list of and interpretation of all results that are significant at the $p < 0.05$ level.

8.2.1 Learning Attitudes Questionnaire

Elliot and Church [14] note that previous studies of learning motivation used a framework which consisted either of a (more contemporary) *performance/mastery* distinction or a (more classical) *approach/avoidance* distinction. In simple terms, the performance/mastery distinction differentiates between students who are motivated to study/learn because they want to do well (e.g. get a high grade) and those who want to learn as much as possible, i.e. master the material. The approach/avoidance distinction (as applied to the specific topic of learning) focuses on the difference between students who are motivated to learn because they seek the rewards associated with success and those students who are motivated to learn because the wish to avoid the negative reward associated with failure. Elliot and Church combine these two types of distinctions into a single set which consists of three motivational goals—the *mastery goal*, the *performance-approach goal*, and the *performance-avoidance goal*. Elliot and Church define these goals in ways similar to the goals in the two scales they were derived from, with a mastery motivation corresponding to an increased willingness to take on difficult tasks, even when the possibility of failure is evident, and also corresponds to a greater enjoyment of the learning process. Performance-approach is associated with a desire to "attain favorable judgments of competence" whereas performance-avoidance is associated with a desire to "avoid unfavorable judgments of competence." Elliot and Church point out that mastery and performance-approach both involve the pursuit of positive outcomes while performance-avoidance involves the avoidance of negative outcomes which, unlike the first two, is said to result in negative features such as anxiety, distraction, procrastination, and feelings of helplessness—this explains why the performance-avoidance measure is inversely related to grade performance.

To test for the presence of each of these three goals in students, Elliot and Church formed a set of 18 questions, with 6 questions dedicated to the measurement of each of the three goals. Elliot and Church borrowed or adapted these questions from a number of other sources on the basis of their having been shown to accurately measure the underlying phenomenon they were meant to detect. They averaged the responses from all six questions in a given category to arrive at a measure of the degree to which a student is motivated by each of the three goals. They also went one step further by using the levels of each of the three motivations to estimate levels of *intrinsic motivation* and *graded performance*, the former having been previously defined as the "enjoyment of or interest in an activity for its own sake," the latter simply being a measure of performance, as measured by grades. Using statistical techniques, they formulated a model which established a mathematical relationship between the level of motivation associated with each of the three goals (mastery, performance-approach, and performance-avoidance) and the intrinsic motivation and graded performance factors. The formula for determining the intrinsic motivation is $Intrinsicmotivation = 0.31 * mastery - 0.26 * performance - avoidance$ and the formula for graded performance is $Gradedperformance = 0.36 * performance - approach - 0.34 * performance - avoidance$. Note that each formula depends negatively on performance-avoidance, but they differ in the positive term—a desire to master material increases motivation, but not grades, and a desire to achieve a performance goal increases grades, but not motivation. Since it may be confusing why a desire to master material does not increase grades, the following passage from the Elliot and Church study may be instructive:[2]

> "Mastery goals seem as likely to prompt the perusal of interesting but peripheral material as they are to induce intensive study of information central to course objectives; optimal processing of peripheral material is of little benefit at examination time."

In our study, we used the 18 Elliot and Church questions in conjunction with seven additional questions regarding career-related goals, resulting in a total of 25 questions. We called this set of questions *the Learning Attitudes Questionnaire (LAQ)* (our own

[2]The Elliot and Church study, in fact, revealed that the highest performing group of all consisted of those students with a high performance-approach score and a *low* mastery score.

name, not used by Elliot and Church) and a list of all 25 questions is given in table A.1. We calculated the levels of expression of each of the three goals, as well as the career-related goal which we had added, by averaging the questions associated with each goal. Then, using the formula provided by Elliot and Church, we calculated predicted levels of intrinsic motivation and graded performance for each student. The resulting data will be presented in two forms—the average scores for all 25 LAQ questions, the resulting scores for the mastery, performance-approach, and performance-avoidance goals, and the derived values for intrinsic motivation and graded performance. For the sake of distinguishing between the LAQ questions themselves and the factors that are derived from them, the three goals and two derived factors will collectively be referred to as *Meta-LAQ* measures.

The LAQ was distributed to students in various forms—in the first two semesters, students were first emailed the LAQ (students provided their responses by sending them in an email reply) and then given a printed copy only if they had not done the electronic version. In the third semester, however, students were first given the print copy, and then the email version because we found the response rate was higher if time was set aside in class for students to do the printed version. We assumed that students' responses to the LAQ questions would not change over the course of the semester and that it therefore did not matter when a particular student answered the LAQ. However, the fact that the LAQ was distributed in the second half of each of the three semesters may be adequate for purposes of comparing data between the three semesters.

Data Analysis

Student responses for the Fall 2002 term (9.01), the Spring 2003 term (9.14), and the Fall 2003 term (9.01) are shown in figures B-8, B-10, and B-12 respectively. A graph showing pooled responses from all three semesters is shown in figure B-14. Note that in the latter two semesters, students were broken down into three groups—those with tablets, those who volunteered for a tablet but did not receive one, and those who did not volunteer for a tablet. Only the latter two groups exist for the Fall 2002 term because no tablets were distributed during that term (except during the final week which was after the LAQ was given in any event).

Looking at the last graph in figure B-14, we can see the overall student opinion is quite positive for a number of these questions:

- Q1. In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.
- Q3. I worry about the possibility of getting a bad grade in this class.
- Q5. It is important for me to understand the content of this course as thoroughly as possible.
- Q10. I want to learn the material in this class so I will be prepared take the more advanced Neuroscience classes in the future.
- Q11. I wish to completely master the material presented in this class.
- Q12. I want to learn as much as possible from this class.
- Q23. I hope to have gained a broader and deeper knowledge of Neuroscience when I am done with this class.

We can also see a fairly negative response for a couple questions:

- Q4. Knowing the material for this class will help me get into medical school.
- Q24. If I don't do well in this class, I will have to change my career plans.

These overall LAQ responses indicate that students are seriously interested in learning the material taught in 9.01/9.14 as thoroughly as possible and are not less interested in material simply because it is difficult, though students are concerned about getting a bad grade. One motivation for this interest in learning is that students want to be prepared for future Neuroscience classes. Overall, students did not seem concerned that failure to perform in the course would affect their career plans (medical school included).

Significant Findings

There are also three significant differences found when using pairwise two-tailed t-testing between the three groups. For question 17, which reads

> I want to learn the material in this class because it will complement some of the non-Neuroscience courses I wish to or have already taken.

there is a significant difference between the volunteers without tablets' responses ($\bar{x} = 5.11$) and the non-volunteers' responses ($\bar{x} = 4.19$) with $p = 0.018$. This may indicate that students who volunteered for a tablet took more relevant classes in the same department than those who did not volunteer for a tablet. As for question 19, which reads

> I often think to myself, "What if I do badly in this class?"

there is a significant difference between tablet users' responses ($\bar{x} = 3.57$) and responses of volunteers without tablets ($\bar{x} = 4.64$) at the $p = 0.035$ level. Since the LAQ was given after students had their tablets, this may indicate an actual effect due to the tablets—perhaps having a tablet increases a student's confidence, either because it causes an actual improvement in the student's performance, or because the student feels that it has the potential to. Finally, for question 23, which is

> I hope to have gained a broader and deeper knowledge of Neuroscience when I am done with this class.

there is a significant, albeit small, difference between tablet users' responses ($\bar{x} = 6.60$) and non-volunteers' responses ($\bar{x} = 6.23$) at the $p = 0.029$ level. This may indicate a greater degree of enthusiasm for learning due to the tablets or it may indicate, since the tablet users volunteered for a tablet, that volunteers were more enthusiastic in general (though the two-tailed t-test comparing all volunteers, that is, those with or without tablets, to non-volunteers was not quite significant). The effect is rather small in any case.

The meta-LAQ items were also calculated, with the results shown in figures B-9, B-11, B-13, and B-15 for the Fall 2002 term, Spring 2003 term, Fall 2003 term, and aggregate data respectively. While the chart depicts the actual values associated with each of the three goals, the two derived values have been normalized for purposes of the graph, with 1 being the lowest theoretically possible value, and 7 being the highest for each factor. Pairwise t-tests indicated no significant differences between the volunteer and non-volunteer groups for any of the five meta-LAQ items for the Fall 2002 term of 9.01. Despite some near-significances, there were also no significant differences between tablet users, volunteers without tablets, and non-volunteers for the Spring 2003 term. Since that semester represents the smallest sample, it is not surprising that significance was not achieved.

The Fall 2003 term of 9.01, however, is a different story. While the performance-approach and career-related goal scores were indistinguishable between the three groups, there was a nearly significant ($p = 0.055$) difference between tablet users and students without tablets (volunteers and non-volunteers alike), with tablet users having the higher mastery score ($\bar{x} = 5.9, s = 0.7$) than the students without tablets ($\bar{x} = 5.3, s = 1.2$). Furthermore, the tablet users had a lower performance-avoidance score ($\bar{x} = 3.7, s = 1.3$) than the students without tablets ($\bar{x} = 4.2, s = 1.5$), though the result was not nearly significant ($p = 0.20$). While these findings were not independently significant, the fact that they are the two factors used in calculating the intrinsic motivation variable resulted in a significant difference in that measure, with tablet users ($\bar{x} = 4.8, s = 0.7$) having a higher intrinsic motivation than both the control group, that is, the volunteers without tablets ($\bar{x} = 4.3, s = 1.1$) with $p = 0.038$ and the set of all students without tablets taken collectively ($\bar{x} = 4.2, s = 1.1$) with $p = 0.030$.

However, there was no significant difference between the three groups in terms of (predicted) graded performance. This is because graded performance depends on the performance-approach goal, not the mastery goal, and while tablet users were higher in their mastery score, they were not higher in their performance-approach score. This might also serve as an explanation as to why tablet users were not found to have higher grades than other students (as will be shown in section 8.2.4)—they are more intrinsically motivated because they care more about mastering the material than other students, and are less afraid of performing poorly, and while their lack of fear of performing badly does increase their grade prediction [3], the fact that tablet users' performance-approach score is the same as the other groups' scores prevented the grade-related effect from being large enough to be detected. What this means for the Paperless Classroom is that tablets may in fact increase students' desire to learn and fully master material, but since a desire for mastery has been shown to be minimal in its impact on grades compared to the performance-approach goal (wanting to get a good grade, for example), tablet users are unfortunately left unrewarded for this mastery. However, if a grading system were constructed that rewarded mastery more than performance-approach, then tablet users would likely have higher grades. In any case, because of the fact that tablet users were found to have significantly higher intrinsic motivation than the control group (volunteers without tablets), it can be inferred that the tablets have a causative effect which increases students' motivation. Tablets only fail to increase students' grades because they do not make students more desirous of a high grade. They do, however, make students less fearful of a bad grade, which results in a weak (and in this study, undetectable) grade increase.

Conclusions

Thus the LAQ served more to characterize the attitudes of 9.01 and 9.14 students than it did to point out differences among the three groups consisting of students with tablets, those who volunteered for a tablet but did not get one, and those who did not volunteer. These three groups were, in all but a few cases, similar in their responses. However, upon using the LAQ data to calculate values of intrinsic motivation, significant findings were made, findings which may explain the underlying effects of the tablets on students more than any other presented in this thesis. Of critical import is the fact that our dependence on grade measures in determining the

[3] The tablet users did, in fact, have a higher grade prediction than both other groups, but the difference was not significant.

impact of tablets on students may obscure other, equally valuable traits which the tablets do influence positively.

8.2.2 Cognitive Styles Analysis

The Cognitive Styles Analysis (CSA) is a computerized test developed by Richard Riding [41] [40], the purpose of which is to determine where an individual falls on each of two dimensions—the *verbaliser-imager* dimension and the *wholist-analytical* dimension. The claim regarding these dimensions is that they are set for an individual early in life and that they affect social behavior, decision making, and learning behavior [44]. There are three means cited by which an individual's specific position on each of these dimensions affects their learning—by interaction with the mode of presentation of material, by influencing an individual's preference for a particular mode of learning, and through influencing an individual's process of active learning strategy formation [44].

Where an individual falls on each axis (i.e. dimension) carries a simple interpretation—an imager learns better from presentations of material which are heavy in pictographic content, presumably because their brain is more well-equipped to process visual information. A verbalizer, on the other hand, will presumably learn better from presentations of material which are rich in textual content because they process verbal information more efficiently.[4] A wholist has an easier time seeing the "big picture" where as the analytic individual will find it easier to think of a system in terms of its individual components.

Sadler-Smith and Riding [44] point out that once an individual's cognitive style (their place on each of the two axes the CSA measures) is known, that individual will know what types of presentations of material they will learn from most easily as well as those types of presentations they will find more challenging. The individual will be able to use this information to seek out presentations of material that use the mode

[4]It would also be reasonable to conclude that textual content should include both printed text and spoken text. Spoken text might, in fact, be considered even more verbal than printed text because reading printed text still requires active use of the visual system whereas listening to spoken text does not.

best suited to their cognitive style while finding ways of coping in situations where the non-preferred presentation modes are being used. Beliefs regarding ones own thought processes, as these are, are sometimes referred to as *metacognitive* beliefs.

The implications of the CSA for the instructor are that, if an instructor knows the cognitive style of the student body being taught, then presentations can be geared to take advantage of the students' cognitive styles. In most cases, students in a course will have a variety of cognitive styles requiring the instructor to provide an equal variety of presentation modes. Providing students with study materials which allow them to take advantage of their cognitive style regardless of which particular style they have is the safest approach.

The actual means of determining where an individual falls on each of the axes is a computerized test [41], in our case a Java applet running from an MIT web server, which presents the user with a series of questions, in three parts.

The first part consists of two types of questions—those which ask whether two items are of the same color, and those which ask whether two items are of the same type. As stated in the instructions, the user must indicate, using the 'm' and 'n' keys on the keyboard, whether the items are or are not the same (in color or type, depending on the question) and must do so as quickly as possible while still being accurate. After providing an answer, the user will receive a brief message stating whether they were right or wrong and then a new question will automatically appear. For example, the user might be asked whether the statement *bread and butter are the same color* is true as in figure B-16. This points out that, in some cases, the question is somewhat ambiguous because rye bread, for example, is not the same color as butter but many lighter breads are. The correct answer in this case is, yes, they are the same color, which is indicative of the fact that many of the questions in this first part of the CSA are asking about prototypes—that is, prototypical bread is the same color as butter. The second type of question in this first section asks the user whether two items are of the same type, asking, for example, whether the statement *skiing and baseball are the same type* is a true statement, as shown in figure B-17. In this case, the answer is yes because skiing and baseball are both types of sports. An example question in which the items are not the same type is *tennis and court are the same type* which is false despite the fact that the two items are clearly related.

The second part of the CSA presents a series of pairs of shapes and asks the user whether these shapes are the same, as in figure B-18. Just as in the first section, the user must answer as quickly as possible using the designated keys on the keyboard.

The final section is similar to the second section but, instead of asking whether two shapes are the same, it asks whether the shape on the left is contained in the shape on the right without allowing the shape on the left to be rotated or scaled in size. An example of a question from this section is shown in figure B-19. Again, the user must answer questions in this section as quickly as possible while still giving accurate answers.

After the user is done with all three sections, the CSA software uses the user's reaction time for each type of question and produces the user's score which consists of their *Wholist-Analytical (WA) ratio* and their *Verbalizer-Imager (VI) ratio* as well as a text label associated with each of these ratios. For the Wholistic-Analytic axis, ratios of 1.02 or below are considered *Wholistic*, those between 1.02 and 1.36 are considered *Intermediate*, and those 1.36 or higher are considered *Analytic*. For the Verbalizer-Imager axis, scores of 0.98 and below are labeled *Verbalizer*, those between 0.98 and 1.10 are labeled *Intermediate* and those 1.10 or above are labeled *Imager* [41].

In the case of the Paperless Classroom, we thought it would be interesting to know if students who volunteered for a tablet had a particular cognitive style or if students with a particular cognitive style performed better in 9.01 or 9.14. The CSA was also useful in profiling our students as a whole, to see if students taking 9.01/9.14 had an overall bias in cognitive style, perhaps making our particular choice of subjects more or less suited to the use of a tablet. We administered the CSA during all three semesters of the paperless classroom. Students' WA and VI ratios were automatically sent to a secure server which I had access to.

Data Analysis

Students' responses for each of the three semesters, as well as pooled data for all three, are shown in scatter plots in figures B-20 through B-23. As was the case for the LAQ, students for the two semesters in which tablets were distributed, Spring and Fall 2003, were broken down into three categories—those with tablets, those who volunteered for a tablet but did not receive one, and those who did not volunteer for a tablet. Only the latter two groups exist for the Fall 2002 term because no tablets were distributed during that term (except during the final week which was after the CSA was administered).

As with the LAQ, we will focus on the aggregate (i.e. pooled) CSA data consisting of data from all three semesters. Looking at the scatter plots reveals that the CSA scores from each of the three groups (tablet users, volunteers without tablets, and non-volunteers) are fairly commingled. However, rather than depending on the naked eye, a pairwise two-tailed t-test performed independently on the WA and VI ratios for these data was used for each semester as well as the aggregate data. Bar graphs showing the means and standard error are given in figures B-24 through B-27. As suggested by the bar graphs, the t-tests found no significant differences among any of the three groups (tablets, volunteers without tablets, non-volunteers) either within a given class or when all three classes were considered as a single dataset.

In terms of overall cognitive styles, we can see from the bar graphs (as well as the scatter plots) that there is significant variation among students in each of the three groups along each of the (WA and VI) dimensions. For the 9.01 Fall 2002 group, there were only volunteers ($\bar{x}_{WA} = 1.00, s_{WA} = 0.25$ (Wholist) and $\bar{x}_{VI} = 1.00, s_{VI} = 0.25$ (Intermediate)) and non-volunteers ($\bar{x}_{WA} = 0.97, s_{WA} = 0.21$ (Wholist) and $\bar{x}_{VI} = 1.10, s_{VI} = 0.10$ (Imager)). For the 9.14 Spring 2003 group, there were tablet users ($\bar{x}_{WA} = 1.00, s_{WA} = 0.19$ (Wholist) and $\bar{x}_{VI} = 1.03, s_{VI} = 0.05$ (Intermediate)), volunteers ($\bar{x}_{WA} = 0.95, s_{WA} = 0.14$ (Wholist) and $\bar{x}_{VI} = 0.95, s_{VI} = 0.06$ (Verbaliser)), and non-volunteers ($\bar{x}_{WA} = 0.94, s_{WA} = 0.13$ (Wholist) and $\bar{x}_{VI} = 1.05, s_{VI} = 0.15$ (Intermediate)). Finally, for the 9.01 Fall 2003 group, there were tablet users

($\bar{x}_{WA} = 1.10, s_{WA} = 0.31$ (Intermediate) and $\bar{x}_{VI} = 1.05, s_{VI} = 0.15$ (Intermediate)), volunteers ($\bar{x}_{WA} = 1.11, s_{WA} = 0.23$ (Intermediate) and $\bar{x}_{VI} = 1.08, s_{VI} = 0.14$ (Intermediate)), and non-volunteers ($\bar{x}_{WA} = 1.04, s_{WA} = 0.23$ (Intermediate) and $\bar{x}_{VI} = 1.03, s_{VI} = 0.16$ (Intermediate)). Students taking 9.01 and 9.14 in the first two semesters would seem to have a slight Wholist bias and even students in the Fall 2003 term of 9.01 were much closer to the Wholist end of the spectrum than they were to the Analytic end of the spectrum, though they did fall within the Intermediate range. This may indicate any number of things because it is impossible to say from these data alone whether it is college students, MIT students, students in the MIT department of Brain and Cognitive Science department, or students taking 9.01 and 9.14 specifically that have a wholist bias. Thus, without comparative data, such as MIT-wide CSA scores, the meaning of this global effect can not be determined. It is even possible that the CSA test we used results in scores biased towards the Wholist end of the Wholist-Analytic spectrum. In fact, Mayer and Massa [30] conducted a study which compared the results from a total of 14 tests designed to measure the Verbal-Imager distinction and checked the results for consistency across tests, as determined by cross-correlation among other methods. They found that while many of the measures used correlated with each other strongly, the CSA only correlated significantly with one of the other 13 measures, with a weak correlation of $r = 0.19$. They conclude with an interesting remark regarding the CSA:

> "The Cognitive Styles Analysis—which we originally listed as a measure of cognitive style—did not load on any of the factors and did not correlate significantly with any other measure. We conclude that we were unable to validate the Verbal-Visual scale of the Cognitive Styles Analysis as a measure of cognitive style or learning preference. In short, we are not able to specify what the Cognitive Styles Analysis measures, but it does not seem to measure what other instrument designers think of as cognitive style or learning preference."

Needless to say, had this study, published in December of 2003, been available during the planning stages of assessment for the Paperless Classroom, we might have used one of the measures that Mayer and Massa found to be consistent with other measures of the Verbal-Imager scale [30].

Conclusions

An underlying assumption is that an individual's cognitive style is innate and cannot be changed so we were not trying to determine whether a student's CSA scores can be changed by having a tablet. The main findings we were looking for, that students with particular styles are more likely to volunteer for a tablet, or that students with particular styles perform better in the courses, could not be supported simply because of the lack of any measurable difference in cognitive styles across groups. However, it is in a sense reassuring to know that the students who received tablets are not so different in their learning styles as to be misrepresentative of the larger student population, which means that our findings regarding these students' use of the tablets will be more applicable to other students.

8.2.3 Matched Surveys

In order to determine student attitudes regarding 9.01/9.14 and the material being taught, their success in organizing class materials and handouts, and their notions regarding tablets and their potential benefits, we formulated a survey which was distributed both at the beginning and the end of the Spring 2003 term of 9.14 as well as the end of the Fall 2003 term of 9.01. A beginning-of-term survey was not offered during the Fall 2003 term due to limitations on the number of surveys we could offer. The questions were identical on each of these three occasions, allowing comparison across surveys.

Also, since we offered the same survey at the beginning and at the end of the Spring 2003 term, the results from those two surveys will serve as the basis for measuring changes over the course of the semester. Although the exact cause of any changes detected in survey responses over the course of the term cannot be attributed to anything in particular, it is reasonable to assume that any changes in attitudes regarding tablets are due to the actual presence of the tablets.

Data Analysis

A list of questions in the matched survey can be found in table A.2. Students were broken down into the same three groups used in aforementioned assessments—namely students with tablets, those who volunteered for a tablet but did not receive one, and those who did not volunteer for a tablet. Recall that students who received tablets were drawn at random from the volunteer pool, thus the volunteers without tablets are a valid control group when compared to those students with tablets. In the survey offered at the beginning of the Spring 2003 term, no tablets had yet been distributed so while the upcoming graphs will indicate a tablet group, in this case it refers to those students who would eventually receive tablets later in the term.

Bar graphs showing the results for the Spring 2003 beginning-of-term survey, Spring 2003 end-of-term survey, and Fall 2003 end-of-term survey are shown in figures B-28, B-29, and B-30 respectively. A graph containing pooled data from both end-of-term surveys (from Spring 2003 and Fall 2003) is given in figure B-31. There is no corresponding graph of pooled beginning-of-term data because no beginning-of-term survey was offered in the Fall 2003 term.

Looking at the aggregate data in figure B-31, we can see that students answers to these questions are generally in the 6-7 range, indicating a mildly positive response to each of the questions. For example, overall student opinion is just slightly on the positive side of neutral for questions such as *do you enjoy your in-class experience.* Note that questions 7, 15, and 16 are not on the 1 to 10 scale the other questions are on but question 15 is the only one requiring explanation—for that question, student responses (originally in the form of letter grades) were converted to a 5-point scale in the graph, 5 being an A, 4.5 being an A/B, 4 being a B, and so on.

I will now briefly characterize overall student opinion regarding each of the tablet-related questions.

- 4. Regardless of your answer to (3), would having a tablet decrease the tedium in your studies in 9.01/9.14? $\bar{x} = 4.94, s = 2.97$

- 6. Would having the tablet improve your understanding of 9.01/9.14 material due to its ability to display all handouts in color (as opposed to black-and-white handouts)? $\bar{x} = 6.35, s = 2.74$

- 7. How many hours per week of your time do you think a tablet would save you? That is, to achieve a given amount of learning or progress, how much less time per week would be required if you had a tablet (negative answers are accepted)? $\bar{x} = 1.02, s = 1.55$

- 8. Would a tablet help you to better organize materials and handouts for 9.01/9.14? $\bar{x} = 7.16, s = 2.97$

- 9. Would a tablet help you to organize your own notes for 9.01/9.14? $\bar{x} = 6.83, s = 3.00$

- 10. Would a tablet help you organize your time better (in any way, not just for 9.01/9.14)? $\bar{x} = 5.97, s = 3.06$

- 14. To whatever extent you feel a tablet might be useful in 9.01/9.14, how much of that usefulness depends on the existence of a stellar site for 9.01/9.14 (1 = none 10 = all)? $\bar{x} = 6.84, s = 2.72$

We can see that, in each case, students are at least neutral about the tablets' effects, with the most positive responses pertaining to the tablet's ability to help them organize materials, handouts, and notes, and to the dependence of the usefulness of the tablet on Stellar. (Stellar was described in section 5.6.1.) We can also see that students, on average, feel that tablets can save them about one hour per week. It is important to remember that these are data from the end of the term, so all students answering these questions had at least some exposure to tablets, either through their peers or simply by seeing the professor use the tablet as a presentation device (and using tablet-specific functions in the process). Thus it can be argued that at the time of these surveys, students were fairly well informed regarding the tablets, certainly more so than in the beginning-of-term survey.

It is also worth noting that 9.14 students' opinions were more positive in general, but since there are many fewer students enrolled in 9.14 each semester than there are in 9.01 (largely because 9.01 is a requirement and 9.14 is not), the mean score for each question is more representative of 9.01 students' opinions. 9.14 students might be more enthusiastic in general since 9.14 is not a required course and the students are therefore only enrolled by choice, not by necessity.

Beginning of Term Survey Findings Three significant results were found when performing pairwise two-tailed t-tests between groups in the beginning-of-term survey (given only in the Spring 2003 term of 9.14). Since the beginning-of-term survey was distributed before tablets were distributed, it will be safe to merge all volunteers, regardless of whether they ultimately received a tablet, into a single group. The other group will simply consist of non-volunteers. These results are as follows.

- 3. Is studying for 9.14 tedious? For volunteers, $\bar{x} = 6.17, s = 2.00$. For non-volunteers, $\bar{x} = 9.00, s = 1.15$. $p = 0.019$

- 4. Regardless of your answer to (3), would having a tablet decrease the tedium in your studies in 9.01/9.14? For volunteers, $\bar{x} = 7.75, s = 1.60$. For non-volunteers, $\bar{x} = 4.25, s = 3.30$. $p = 0.012$

- 5. Regardless of your answer to (3), would having learning software customized for 9.14 decrease the tedium in your 9.14 studying? For volunteers, $\bar{x} = 7.83, s = 1.40$. For non-volunteers, $\bar{x} = 5.25, s = 2.50$. $p = 0.020$

Interestingly, we can conclude from these data that those who volunteered for tablets not only find studying for 9.14 less tedious than the others, but were also more optimistic regarding the extent to which technology, in this case tablets and learning software, could decrease their study tedium. We can also use this finding to get at one potential motivation for a student to volunteer for a tablet—volunteers may volunteer in part because they have a predisposition to believe that the tablet will help make studying less tedious. However, these data alone do not prove that such a predisposition is the actual cause of volunteering, they simply suggest the possibility of such a connection.

End of Term Survey Findings There were a number of significant findings when the three groups (tablets, volunteers, non-volunteers) were compared with pairwise two-tailed t-tests. Since the end-of-term survey was offered both in the Spring and Fall of 2003, the data from those two semesters will be merged for purposes of comparison. Had these two semesters of students differed so much as to be incomparable, it would have resulted in an increase in standard error that would have prevented findings from being significant—however, since there were a number of significant findings, it would seem that the two semesters are comparable.

Also note that in some cases, volunteers with and without tablets are treated as a single group, or students without tablets, whether or not they volunteered, are combined into a single group. Findings are only reported in this manner if the complementary group is significantly different from both of the subgroups it is being compared to. Also, unless stated otherwise, the significance level is lower (better) when the groups in question are merged than when they are considered separately. In question 7, for example, tablet users gave a response that was higher than the volunteers without tablets with a significance level of $p = 0.037$ and higher than non-volunteers with a significance level of $p = 0.009$. However, the tablet users' response was higher than all students without tablets, taken collectively, with a significance level of $p = 0.003$. Thus the finding is reported as tablet users being significantly different from all students without tablets. The findings and their significance levels are shown below.

- 1. Do you enjoy your in-class experience in 9.01/9.14? For tablet users, $\bar{x} = 6.68, s = 2.13$. For volunteers without tablets, $\bar{x} = 5.38, s = 2.42$. $p = 0.049$

- 2. Do you enjoy time spent on 9.01/9.14 outside of lecture? For tablet users, $\bar{x} = 6.84, s = 1.48$. For volunteers without tablets, $\bar{x} = 5.25, s = 2.31$. $p = 0.004$

- 4. Regardless of your answer to (3), would having a tablet decrease the tedium in your studies in 9.01/9.14? For volunteers (with or without tablets), $\bar{x} = 5.85, s = 2.90$. For non-volunteers, $\bar{x} = 3.34, s = 2.39$. $p = 0.0002$

- 6. Would having the tablet improve your understanding of 9.01/9.14 material due to its ability to display all handouts in color (as opposed to black-and-white handouts)? For tablet users, $\bar{x} = 7.42, s = 2.35$. For non-volunteers, $\bar{x} = 5.17, s = 2.89$. $p = 0.002$

- 7. How many hours per week of your time do you think a tablet would save you? That is, to achieve a given amount of learning or progress, how much less time per week would be required if you had a tablet (negative answers are accepted)? For tablet users, $\bar{x} = 1.67, s = 1.81$. For students without tablets, $\bar{x} = 0.62, s = 1.23$. $p = 0.003$

- 8. Would a tablet help you to better organize materials and handouts for 9.14? For all volunteers (those with or without tablets), $\bar{x} = 8.21, s = 2.25$. For non-volunteers, $\bar{x} = 5.31, s = 3.21$. $p = 10^(- 5)$

- 9. Would a tablet help you to organize your own notes for 9.14? For all volunteers (those with or without tablets), $\bar{x} = 7.72, s = 2.76$. For non-volunteers, $\bar{x} = 5.28, s = 2.80$. $p = 0.0003$ ($p = 0.0001$ and $p = 0.04$ when tablet users and volunteers without tablets respectively are compared to non-volunteers.)

- 10. Would a tablet help you organize your time better (in any way, not just for 9.14)? For tablet users, $\bar{x} = 7.11, s = 2.91$. For non-volunteers, $\bar{x} = 4.62, s = 2.66$. $p = 0.001$

- 11. Are you currently successful at organizing materials and handouts for 9.01/9.14? For tablet users, $\bar{x} = 8.63, s = 1.32$. For all students without tablets, $\bar{x} = 6.98, s = 2.58$. $p = 0.0015$ (In this case, $p = 0.0008$ and $p = 0.008$ when tablet users are compared to volunteers without tablets and non-volunteers separately.)

- 12. Are you currently successful at organizing your own notes for 9.01/9.14? For tablet users, $\bar{x} = 8.24, s = 1.59$. For all students without tablets, $\bar{x} = 7.08, s = 2.31$. $p = 0.016$

- 14. To whatever extent you feel a tablet might be useful in 9.14, how much of that usefulness depends on the existence of a stellar site for 9.14 (1 = none 10 = all)? For tablet users, $\bar{x} = 7.45, s = 2.26$. For non-volunteers, $\bar{x} = 5.86, s = 3.13$. $p = 0.03$ (While volunteers without tablets were not significantly different from non-volunteers, all volunteers taken collectively are significantly different from non-volunteers with $p = 0.014$.)

We draw a number of conclusions regarding the findings above. First, tablet users enjoyed their experience working on 9.01/9.14 inside and outside of class more than volunteers without tablets. While this could be attributed to sour grapes on the part of students who did not receive a tablet but wanted one, it could also be interpreted as a causative effect—tablets increase enjoyment of studying both within and outside the classroom. Since the volunteers without tablets represent a proper control group, this finding is particularly salient.

It was also found that tablet users are more convinced than other students that the tablets can save them time and that they are currently successful at organizing their materials, handouts, and notes. Since these findings were also significant when tablet users were compared only against volunteers without tablets, and since the volunteers without tablets constitute a proper control, we can infer causation—having the tablets did in fact make students more organized (to the extent that self-report is accurate).

Volunteers in general were more convinced that tablets could help them organize their materials, handouts, notes, and time, and reduce study tedium, and were also more convinced that the usefulness of the tablets depended on Stellar. This is probably indicative of preexisting notions that would have been shown in a beginning-of-term survey had it been offered in the Fall 2003 term (the data from the Spring 2003 suffered from a small sample size). We cannot infer with confidence, but can consider it a possibility, that these notions about the potential for tablets to increase organization and reduce study tedium partly constitute the underlying motivation for students to volunteer for a tablet in the first place. Saying that the tablet's usefulness depends on Stellar is not necessarily saying something bad about the tablets—it could be interpreted as saying something especially good about the tablet-Stellar combination—separate questions asking about the tablet's usefulness with and without Stellar might have teased out the answer.

Beginning and End of Term Comparison One of the goals of the matched surveys was to compare student opinion at beginning- and end-of-term. Since the Spring 2003 term of 9.14 is the only term in which the surveys were offered and both the beginning and the end of the course, this comparison will be limited to that semester. The comparison will be made by performing two-tailed t-tests between the beginning- and end-of-term data for each of the three groups of students—those with tablets, those who volunteered but did not receive a tablet, and those who did not volunteer for a tablet.

Unfortunately, the total number of students in 9.14 was sufficiently small (about 25) that, when combined with the fact that a less than optimal response rate was achieved, the sample size for both non-tablet groups was quite small ($n = 3 or 4$). Thus while simply looking at the means and standard errors might suggest a significant change, the small sample size is taken into account in a t-test and significance is thus greatly reduced (that is, the p-value is increased). In retrospect, I wish I had performed the beginning-of-term survey in the Fall 2003 term instead of one of the other surveys. In any case, the before and after comparisons for the tablet users, volunteers without tablets, and non-volunteers are given in figures B-32, B-33, and B-34 respectively. A class-wide comparison which combines all three groups is given in figure B-35. Despite the small sample size, there were two significant findings among all these comparisons as well as many nearly significant results which will not be reported. Without a doubt, had the sample size been larger, a number of additional interesting findings would have been made. The two significant findings are given below.

- 11. Are you currently successful at organizing materials and handouts for 9.01/9.14? For tablet users at the beginning of the term (prior to receiving, or knowing they would receive, a tablet), $\bar{x} = 6.89, s = 1.83$. For tablet users at the end of the term, $\bar{x} = 8.89, s = 1.05$. $p = 0.012$

- 12. Are you currently successful at organizing your own notes for 9.01/9.14? For tablet users at the beginning of the term (prior to receiving, or knowing they would receive, a tablet), $\bar{x} = 6.72, s = 1.39$. For tablet users at the end of the term, $\bar{x} = 8.5, s = 1.32$. $p = 0.014$

These findings serve to reinforce the finding in section 8.2.3 that tablets have the causative effect of increasing students' organization of materials, handouts, and notes. It is further reinforced by the fact that the control group, volunteers without tablets, did not experience a corresponding increase in organization. Rather, they experienced a decrease in organization, albeit not at a significant level.

Conclusions

The significant results from the surveys, in virtually every case, reflect well upon the tablets. Multiple findings support the notion that tablets increase organization of materials, handouts, and notes. It would also appear to be the case that students' belief that tablets can help them with organization of materials, handouts, and notes, as well as reduce study tedium, are underlying motivational factors for volunteering to receive a tablet, though additional study would be required to solidify that finding. It would also seem that students who volunteer for tablets may be generally more receptive to technology used for purposes of learning.

8.2.4 Grade Data

The effect of tablets on grades may be the single most important thing to determine, more for practical reasons than for scientific ones. Students are clearly interested in improving their grades, and students' parents tend to care about their grades as well. Grades, at least at the undergraduate level, are the most accepted way of conveying to others (a graduate school or employer, for example) the extent to which a student has mastered material. Furthermore, in the ideal case, grades actually do reflect the extent to which a student has mastered material so it makes sense to use them as the most accurate measure of mastery available. Since the goal of the Paperless Classroom is to eliminate paper while maintaining or increasing the students' performance, it is necessary to assess tablets' impact on performance, and we will use grade data to do so.

While 9.01 and 9.14 are fairly similar courses, they are arguably sufficiently dissimilar in content and grading scale to make a comparison across semesters difficult. Thus, we will consider grade data separately for each course. In the case of the Fall 2002 term of 9.01, tablets were not distributed until the last week of classes and thus all students from that semester will be considered volunteers or non-volunteers. Comparing volunteers' grades to those of non-volunteers is still useful because it allows us to determine whether those who volunteer for tablets have a tendency to perform at a different level, in terms of grades, than non-volunteers. Grade data for each semester consist of weekly quizzes, papers and/or homework, a midterm exam, a final exam, and a final letter grade determined from the other grade measures. We will also consider attendance rate for the Spring and Fall 2003 terms, but since attendance was not taken daily, we will simply use the number of missed weekly quizzes as an estimate of overall attendance (or lack thereof). Figures B-36, B-37, and B-38 indicate the grade data for each of these measures for the Fall 2002, Spring 2003, and Fall 2003 semesters respectively.

Data Analysis

For each of these grade measures, data have been normalized to a scale from 0 to 10, with 10 corresponding to the highest possible performance level.

9.01, Fall 2002 The only significant difference found in grade data from the Fall 2002 semester was that volunteers ($\bar{x} = 7.05, s = 2.28$) had slightly lower paper grades than non-volunteers ($\bar{x} = 7.89, s = 0.87$), with $p = 0.049$. A peek at the graph in figure B-36 reveals that non-volunteers have higher performance in each grade category though these differences are slight and non statistically significant. Even so, should it turn out that volunteers have lower grades overall, it might be possible to conclude that non-volunteers do not volunteer because they are already doing well without a tablet. Non-volunteers may even be doing well specifically because their learning style does not require them to have a tablet whereas those who volunteer know their own learning style well enough to predict that a tablet would help them. This is, in any case, speculative and the finding regarding paper grades was only marginally significant.

9.14, Spring 2003 Pairwise two-tailed t-tests performed between each of the three groups (tablets, volunteers, non-volunteers) revealed no significant results. This is no doubt due largely to the fact that the number of students in 9.14 is less than a third of the number of students typically in 9.01. It would have been especially difficult to find any differences between tablet users and their preferred control, the volunteers without tablets, because the total number of volunteers without tablets was extremely small—there were in fact only three such students.

9.01, Fall 2003 Unlike 9.14, 9.01 has enough students to allow any reasonably large effect to be detected.[5]

Unfortunately, the statistical power was not quite what it needed to be as a number of nearly significant results were found while only one truly significant result existed. This can be seen in the graph for this semester (figure B-38) in which tablet users' mean performance was higher than both other groups for many grade measures, in some cases temptingly close to significance. Tablet users' quiz grades ($\bar{x} = 7.78, s = 1.42$), for example, were higher than those of volunteers without tablets ($\bar{x} = 6.56, s = 2.52$) with $p = 0.052$. This may be related to the lone significant finding, namely that tablet users ($\bar{x} = 9.72, s = 0.54$) had better attendance than

[5]In the case of the Fall 2003 term, there were 81 students who took the course to completion, i.e. did not drop the class or receive an incomplete. There were 22 students with tablets, 24 who volunteered for a tablet but did not receive one, and 35 students who did not volunteer for a tablet. This constitutes a nice breakdown of students into the three groups being compared.

volunteers without tablets ($\bar{x} = 8.70, s = 1.97$), with $p = 0.024$. This is because the quiz score shown in the graph is actually the students' average quiz score, counting missed quizzes as zeros. Since the attendance score is based upon the number of missed quizzes, it is not hard to see why tablet users quiz average might be higher. However, even after removing missed quizzes from the calculation, tablet users' quiz average was slightly higher, though not by a statistically significant amount. It is, however, worth noting that the lowest final grade received by any tablet user during this term was a B-, where as the lowest in the class was a C-. While this could be due to the larger sample of non-tablet users, it brings up an important possibility: the ceiling effect may partially obscure the effect of the tablets—students who would have gotten an A without the tablet might have gotten an A or an A+ with the tablet. The improvement is small because there's little room for improvement. Students with lower grades have more room for improvement and the tablet user with a B- might have done much worse without the tablet. This fact does not show up in the statistics, however, because enough of the tablet users are near the ceiling to make the overall increase in student grades fairly small. One way to solve this problem would be to give harder exams, eliminating the ceiling. Final grades could still be curved for purposes of fairness.

Conclusions

Thus, in what was arguably the most important arena, we found scant evidence of any impact due to tablets. However, figure B-38 suggests that a larger sample is needed before the possibility that tablets affect grades is ruled out. Although insignificant, the fact that tablet users in the Fall 2003 term (by far the largest dataset available to us) outperformed both other groups in every grade category warrants further attention in the form of a larger sample. Furthermore, as mentioned in section 8.2.1, it was found that students with tablets cared more about mastering material than did other students. Unfortunately, it would appear that a mastery goal alone does not increase grades and that a performance-approach goal (one in which the student specifically cares about performing well, as opposed to mastering the material) would be more likely to cause a grade increase. There was, however, also the indication that tablet users have a lower performance-avoidance attribute than other students, and this may have resulted in the noticeable but statistically insignificant grade increase found for tablet users. In any case, the goal of the Paperless Classroom was to remove paper while maintaining or increasing the performance of students, and it is clear that the tablets have succeeded in meeting those terms.

8.2.5 Interviews

In both of the semesters in which tablets were distributed (Spring and Fall 2003), I conducted personal interviews with every student who received a tablet. I performed these interviews no sooner than the last week of classes and no later than the week just after classes (finals week). While the questions in these interviews could have been asked in a printed survey, the personal contact with students afforded me some flexibility in exploring avenues of discussion I might not have considered putting in a survey. In any case, it was refreshing to hear students' experiences with tablets first hand. Table A.3 contains a list of questions which I asked in every interview, and while discourse was not limited to these questions, I will focus on them as they were the main points being explored by summarizing student responses for each question in turn.

Frequency of Use

When asked what percentage of days they used their tablet in 9.01/9.14 (of the days they attended class), the vast majority replied that they used the tablet every day, with a few missing 2-3 classes, and a few using it as little as 70-80

- Wireless not working (x2)
- There were file saving problems (x1)
- One day the tablet was really slow for some reason (x1)
- Low battery, didn't know we had spare batteries for them (x2)

- Professor didn't put the Journal files online (x3)
- No safe place to put it after class on Fridays (x1)
- Girlfriend had it (x1)
- Forgot to bring the tablet (x2)

One could label the first three items *unpreventable or unanticipated technical problems*, the next two items *preventable technical problems* and the last three *preventable non-technical problems* (though the case of the student not having any place to put the tablet after class may not have been preventable). There were 4, 5, and 3-4 responses in these categories respectively, a fairly equal number of each. It has already been established in section 7.3.1 that problems with the wireless network constitute the single largest technical problem, and one can only hope that this still-evolving technology will become more robust in the near future. However, as noted in that section, it is possible that some of the wireless problems were due to an overtaxed access point and this carries with it a simple solution—addition of or replacement of access points. The other problems were either highly infrequent or human-correctable and thus pose no major threat. In any event, the overall rate of tablet use within 9.01/9.14 was (reportedly) quite high. I also informally observed students in class and it was a rare event indeed that a tablet user was not using his or her tablet in lecture.

Use in Other Classes

When asked whether they used their tablets in other classes besides 9.01/9.14, students gave a variety of answers. In total, students used the tablet as a tablet (i.e. to take notes or draw with the stylus, not just typing with the keyboard) for classes in Biology, Brain and Cognitive Science, Linguistics, Political Science, and Writing . When using the stylus, students either took notes on a blank Journal page or converted an online PDF version of the lecture notes into the Journal format and took notes on the Journal version. One student also submitted homework by converting

Journal files back into PDFs and then sending them to the professor. Three students asked their instructor to post the PDF lecture notes before class (instead of afterwards) so they could take notes in class. In each case, the instructors did as the students asked.

Students used the tablets as laptops (i.e. without using the stylus, making use of the built-in keyboard and mouse) for classes in Architecture, Chemistry, Economics, Foreign Language, Literature, Music, and Physics (as well as the subjects above in which they used the stylus). For example, students used the tablets to write papers, take typed notes when it was deemed unnecessary to have handwritten notes, visit course websites, and view problem sets. When asked why they did not use the tablet for taking notes in a particular course, students provided a variety of reasons:

- Student doesn't attend lecture in the first place
- Student doesn't feel the need to take notes in the particular course
- In-class use is not allowed/appropriate (e.g. Foreign language courses, Chemistry laboratory)
- Complete, detailed lecture notes are already made available
- Inadequate digitizer resolution and/or calibration (e.g. Chemistry, drawing tiny molecules)
- Inadequate digitizer speed (unable to keep up with rapid, detailed note-taking) (Acer x2)
- Student is already used to paper-based study system (received the tablet in the middle of the term)
- Electronic versions of lecture notes and handouts are not available, so they had to use paper versions
- Didn't know you could convert PDFs (and other files) to Journal format

The first four reasons are related to a lack of need to take notes in general, so they clearly don't reflect any shortcoming in the tablets. The next two items are actual limitations of the tablet hardware, in this case the digitizer. While one of the benefits of the tablet is that it allows notes from any subject to be taken just as they would on paper, including things like molecular diagrams that certainly can't be entered using a keyboard, it would appear that the technology is not quite refined enough for some students, particularly those used to taking intricate, detailed notes in courses such as chemistry. It is quite probable that these students were used to writing things very small on paper, and this taxed the limits of what the tablet could handle. There were other students, for example, who took similar chemistry courses and reported no such difficultly. However, it is true than it is harder to write with extreme detail using the tablets and this is an issue that will hopefully be addressed in future generations of tablets.

The last three items are things that would improve as the Paperless Classroom becomes more pervasive. In a less experimental implementation of the paperless classroom, students would never receive tablets partway through the term. Electronic versions of lecture notes would be more prevalent, and more accessible online, and students would be more familiar with the tricks of the tablet trade, such as how to convert any file to the Journal format.

From this data, it was clear that students were most inclined to use the tablet under either of the following conditions:

- Electronic versions of lecture slides were available and were posted online before class either from day one, or at the request of a tablet user

- No lecture notes were available but there was still a need to take significant amounts of freehand notes, and the notes were not so detailed as to exceed the resolution and/or calibration accuracy of the digitizer

General Positive Comments

When prompted to provide any positive comments they might have on the tablets or the way they were used in the Paperless Classroom, students provided the following types of responses:

- Windows Journal is amazingly useful, it lets you type and write (with stylus) at the same time
- It's easier to take notes now because you don't have to switch between colored pens/pencils and can erase colored pens
- Colored diagrams and pictures in handouts very useful, I used to have to label everything on black-and-white printouts
- The battery life is excellent
- Built-in wireless lets you go online anywhere on campus
- The tablets are very light—much lighter than a laptop. You can work on homework whenever and wherever, and you don't have to carry a big binder. I couldn't possibly have taken printed versions of all the notes with me everywhere
- Tablets make class more interesting—I look forward to using it
- With the tablet you have increased organization and a decreased chance of losing things (e.g. notes)
- The tablet is an advantage on days when the printouts weren't ready in time
- You could quickly tell where the professor was (in lecture) because his page numbers on the overhead matched my page numbers on the tablet (both student and Professor were using Journal to view and annotate the lecture slides)

Many of these comments agree with the ideas laid out in chapter 2—namely that tablets provide the benefit of colored note-taking and colored viewing of lecture slides, that the tablets are highly portable and usable anywhere on campus thanks to built-in wireless, and that tablets promote increased organization of materials. Somewhat novel responses include the notion that the tablet is a motivator—that students look forward to using the tablet presumably either because it's novel or simply less drab than paper. Some students even described the tablet as being like a little friend and one student nicknamed her tablet. While it may at first seem superfluous, the formation of a bond between tablet and user may be worth investigating.

General Negative Comments

Students also gave a variety of negative aspects of the tablets and their use in the paperless classroom, these items are listed below.

- It would have been better if all classes had online material so the tablet could be used for everything
- I would have liked to have had the tablet from the very beginning of the term
- I had to enable/disable wireless connection every time I went to a new location, the wireless was flaky in general
- There was occasional buggy behavior from stylus/digitizer
- The tablet sometimes lags behind if I write really fast
- The tablet got really hot
- The lack of a built-in CD-ROM was occasionally a pain
- The screen is too small (10.4") compared to regular paper
- It's tiring looking at the screen too long
- Lights in the lecture hall produced glare on tablet screen
- Writing on the tablet is slower because you have to keep zooming in and out
- You can't flip through it like you would with a book

- You're in trouble if you forget to charge the battery
- When it doesn't work you lose everything

The first two items would be improved with a more widespread, less experimental implementation of the paperless classroom. The next four problems are hardware issues, the same issues that keep showing up—wireless, digitizer, and a new item—overheating. The next four items pertain to features of the tablets or properties of viewing things on computer screens in general. As mentioned in chapter 6, the price we pay for having an ultraportable device is reduced screen size (as well as the actual monetary price increase). There is little to be done for this, but the benefits far outweigh the drawbacks.

The issue of glare is worth considering and brings up an important quandary regarding partial implementations of the paperless classroom—as far as lighting is concerned, the needs of students using paper are in direct conflict with the needs of students using tablets. One solution would be to slightly reduce lighting at least in part of the room, though this may not always be possible. In any case, only one student mentioned glare so while it may be a problem, it is not a serious one.

The remaining items are general advantages of paper over tablets and computers in general. The need to zoom in and out may be reduced as digitizer technologies improve in resolution. The fact that a malfunctioning tablet completely prevents the student from accessing material is true, unless the student undergoes the recommended backup procedure in which case loss of data is fairly limited. It is nonetheless true that paper is less likely to experience a malfunction than a tablet.

Startup During Lecture

One concern we had was that since students using tablets have to power on their tablets, connect to the wireless network, visit the Stellar site, and download and open the lecture slides, they might not be ready to take notes when the professor begins lecture. We asked students whether they experienced this problem and about a third of the students said they were never behind at the beginning of class. A few students said they were only behind on one or two occasions due to exceptional circumstances (e.g. the tablet crashing) and the remaining students said they were between one and five minutes behind each day, but that it didn't affect them very much. Students' reasons for being behind on a given day included:

- The lecture slides weren't posted online early enough
- Students have less time to boot tablet and download slides on quiz days
- There was difficulty getting on wireless or wireless was slow

Of these items, the first is quite easily corrected, provided a change in the habits of the professor. The second is simply a consequence of the fact that, on quiz days, students must take a quiz at the beginning of class, after which the professor is always ready to start lecture immediately, giving the students less time than usual to download the day's lecture slides. This is correctable, given that the professor is willing to wait an extra couple of minutes before starting lectures on quiz days. The third item harks back to Public Enemy Number One—wireless problems. All that can be said about wireless issues has already been said.

Software Used

We also asked students to provide a list, from memory, of the software they had used on the tablets. We asked them to state for each piece of software whether they used it daily (or almost daily, i.e. three times a week or more), weekly, or just occasionally. Tables A.4, A.5, and A.6 list software used by students with each of these frequencies, respectively. The number of students claming use of a particular piece of software is given to the left of each item.

We can see from these data that students used the tablets for a variety of tasks, generally the ones you might expect, with the most frequently used programs being Windows Journal, web browsers (Internet Explorer, Opera, and Netscape), AOL Instant Messenger, and productivity applications such as Microsoft Word. Students used a number of entertainment-related applications such as Windows Media Player, RealPlayer, and various Windows games.

Organization of Files

Because one of the benefits of the tablet was believed to be that it made organization of materials, handouts, and notes easier, we asked students how, specifically, they stored their schoolwork (including 9.01/9.14 notes) on their tablets. We received the following responses, with the number of students giving each response given in parenthesis:

- Stored most files in *My Documents*, sometimes using separate folders for each course (12)
- Stored most files in *My Notes* (under *My Documents*) and had separate folders for each course (7)
- Stored most files on the Desktop, with separate folders for each course or different folders for lecture slides, other handouts, study questions, etc (5)
- Created folders for each course in *c:* (2)
- Kept recent files on the desktop and moved older files into folders elsewhere, e.g. *My Notes* (2)

Thus, the majority of students used folders to organize materials by course, and many broke materials for a given course down into further categories, with a subfolder for each category. For their root level (the folder containing all of their course folders), students tended to use the locations encouraged by Windows, namely *My Documents* or *My Notes* which resides inside *My Documents* on Tablet XP. This represents use of the hierarchical storage system described as being a benefit of computer storage in general in section 2.1.

Note-taking Habits

When asked how their note-taking might have changed as a result of having a tablet (using Windows Journal), students gave the following responses, with number of students providing a given reply in parenthesis:

- Taking notes is the same as before except with color (16)
- I took fewer notes because writing is was slower on the tablet (2)
- I took fewer notes because my notes became sloppier and I had to go back and fix them (1)
- I'm able to take more notes because typing speech is faster with the keyboard (1)
- I'm able to take more notes because switching colored pens/highlighters is faster (1)
- I'm able to take more notes because you can select text and reduce it on the page (1)
- I use the keyboard for speech, and stylus for diagrams (2)
- I didn't take notes at all until getting the tablet, and started taking notes because of the color (1)
- My notes became much neater with tablet (1)
- I'm more inclined to edit diagrams (1)
- My notes are more informative because of color coding (1)

An overwhelming number of the students mentioned the addition of color as being the primary change in note-taking as a result of having a tablet. When asked how they used color, students replied that they used it to draw different pathways, to indicate specific neurons, separate parts/areas (e.g. of the brain), to circle/highlight, draw directly on diagrams, and indicate a change in topic. Direct evidence supporting these statements will be provided in section 8.2.7 which describes direct observations of students' notes. Students cited increases and decreases in note-taking speed in equal numbers, citing various reasons. Surprisingly, some students frequently switch between use of the keyboard and the stylus, using the keyboard for textual content

(Windows Journal allows text boxes to be inserted anywhere in a document) and the stylus for diagrams.[6]

Modification of Notes

One advantage of tablets is that they make it even easier to quickly recall information in general, including previously taken notes. This led us to ask students whether they ever changed their notes after the lecture in which they were originally taken. We received the following responses (the number of students responding in a given way is in parenthesis):

- No, I do not go back and change my notes later (5)
- Yes, I change my notes while listening to mp3 recording of lecture (because of missed lecture, review of unclear material, etc) (9)
- Yes, I change my notes while reviewing (studying for quiz/exam, doing study questions, assigned readings), new findings would be added to notes (5)
- Yes, I change my notes if, when studying with someone, a gap or discrepancy in our notes was discovered (2)
- Yes, I change my notes to improve my handwriting since it's sloppier than on paper (1)
- I change my notes only when the professor goes over old material in class (1)

From this we can see that the majority of students do go back and change their old notes, and of those who do, the majority do so while listening to the mp3 recordings of lecture which are posted to Stellar after lecture each day. Owing to the information density of 9.01 and 9.14, many students find it necessary to review the lecture by listening to the recording, often while going through the lecture slides, and it is interesting to find out that this behavior persists when tablets are being used instead

[6]This agrees with my personal feelings regarding keyboards and tablets—the keyboard is an indispensable input device to be used in conjunction with, not replaced by, the stylus.

of paper. These data would certainly seem to suggest that the tablets are suited to the task of revisiting and editing old material.

Study Groups

Curious as to how tablets affect (academic) social behavior such as interaction with a study group, we asked students how the tablets might have affected their meetings with study partners. We received the following responses:

- No (20)
- Yes, they would both look at tablet instead of printed notes because the tablet displayed notes in color. Also, she was able to access things faster so she would tend to be the one to look things up in her notes if there was a question. (1)
- Yes, she uses her tablet and she and the others use their paper notes—they complement each other because tablet people can pull stuff up faster but other people have more detailed notes. (1)
- Yes, two (including him) out of six in the group have tablets. They use the tablets for looking at their notes during studying, and can also listen to lectures. Non-tablet users will play with them during these sessions—it's become a pretty popular toy. (1)
- Yes, she accesses her notes, and occasionally draws on it to demonstrate concepts. Other group members thought she was lucky and wished they had one. (1)
- Yes, all three of them had tablets, but at first only one of them had a tablet and they would take turns using it to take notes in class. (1)

While most students did not have a study group, we received some interesting responses from those that did. There are two separate mentions of the tablet's being able to access material more quickly, something which is most likely related to the organizational properties of the tablet, as mentioned in section 2.1. One student noted that the tablet allows them to listen to the mp3 recordings of lecture, which is an example of ubiquity of access as described in section 2.3. Finally, it is interesting to note that, in at least two cases, the tablet was passed around or shared in groups where there were fewer tablets than students.

Tablets in the Future?

While somewhat redundant with our request for general pros and cons of tablets given in sections 8.2.5 and 8.2.5, we wanted to specifically ask students whether they thought tablets should be used in 9.01/9.14 or classes like it in the future. Here is how they responded:

- Yes, with little or no hesitation (17)
- Yes, but they may not be for everyone (e.g. because paper can be just as good) (4)
- Yes, if issues (e.g. battery life) can be addressed (1)

Students cited the following specific reasons for supporting the paperless classroom in the future (since no negative responses were given, this list consists only of reasons in favor of the paperless classroom):

- Better organization; can't lose notes (6)
- It's more accessible resulting in more time spent on material (2)
- Tablet increases motivation to study or made studying more fun (2)
- Reduces stress because you know that if you have a tablet then you have everything you need (1)
- Saves time (1)
- Don't have to carry around a sack of paper (1)

- Can take down more notes (e.g. because of having both stylus and keyboard) (1)
- Ease of taking notes and/or quality of notes is higher (1)
- Could mail each other notes for missed classes (1)
- "It's the beginning of a really positive initiative to create an entirely paperless academic environment" (1)

We can see that the vast majority of students fully support the use of tablets in the future, though it would be reasonable to argue that since this was a personal interview, responses might be biased. However, students seemed fairly willing to give negative feedback in prior questions so it is my personal opinion that these responses are fairly representative of students' true feelings. Reasons for hesitation among students who were hesitant primarily consisted of doubts that tablets were significantly better than paper as well as a single concern about battery life. Recall that this does not mean that students had no other negative comments, it simply means that they are the only items perceived as potential critical problems with the paperless classroom. In terms of reasons to keep the paperless classroom, organizational benefits were the most frequently cited, but a number of other reasons were given, each generally in agreement with reasons already cited in chapter 2. The final comment is amusing and inspiring at the same time.

Other Study Equipment

In order to determine how having a tablet might have changed tablet users' use of other computers such as a desktop, laptop, or *Athena*, the public computing environment at MIT, we asked students to describe their usage of each of these after having gotten used to having the tablet. What follows is a list of student uses for each of these computer types.

Tablet Usage

- Anytime they're not at home (9)
- Schoolwork only (5)
- Everything (4)
- Same things the laptop used to be used for (1)
- Writing out answers to a problem set while viewing the questions on a desktop machine or Athena (1)

Laptop Usage

- At home only (e.g. because it's too big to bring elsewhere) (9)
- Everything except taking notes in 9.01/9.14 (4)
- Going online (2)
- Writing papers (1)
- Just for accessing old files not on the tablet (1)

Desktop Usage

- Most things while at home (6)
- Entertainment (e.g. movies, games) primarily (1)

Athena Usage

- Printing (11)
- Email (5)
- Downloading stuff, e.g. problem sets (2)
- Matlab (2)

Looking at the tablet usages, we can see that most students described their usage as being what one would normally expect a laptop to be used for—any use that requires portability, i.e. any time students aren't at home. Interestingly, students used their laptops primarily for what we would expect a desktop to be used for—anything they do while at home. Most students responding in this fashion specifically identified the size or weight of their laptop as being the main factor that kept it anchored on their desk at home. However, some students continued to use their laptops for everything except taking notes in 9.01/9.14, stating that they had all their files on the laptop so it was still their main machine. In fact, many students noted that they would have used the tablet for more tasks if they didn't have to give it back at the end of the term. We can see that, of those students who had a desktop, most continued to use it for most things while they were at home. Finally, *Athena* usage consisted almost entirely of printing and email tasks which is ironic given that the tablets render each of these usages unnecessary (by eliminating paper entirely and by providing a means of connecting to the wireless network from anywhere on campus, for email among other things). The most significant finding here is the affirmation of our belief that portability is a critical feature which makes the tablets useful and appropriate for use in the paperless classroom.

Tablets as Blackboard Replacement

Our final question aimed to determine whether students benefited from the professor's use of a tablet in lecture as a presentation device, specifically whether his using the stylus to draw diagrams during lecture (instead of using the blackboard) was useful. Students gave the following responses:

- Yes, no specific reason given (6)
- Yes, you can follow along and draw the same thing with your tablet (5)
- Yes, seeing the actual pathway is better than seeing him point to it with a laser (2)

- Yes, but I wish he would post them online (2)
- Yes, because then we're doing the same thing he is (i.e. using Windows Journal); it helps you keep your place (2)
- Yes, I wish he would do it even more (1)
- Yes, it's better than a blackboard because it's really big so you can see it much better (1)
- Yes, makes it clearer what part of the diagram he's talking about (1)
- Yes, but I wish he drew things more slowly (1)
- Yes, seeing him trace the tracts instead of pointing out one of ten black lines really helps (1)
- Yes, it helps you visualize things (1)

The data indicate that all students liked it when the professor used the tablet in class, though a few cited no specific reason. The most commonly cited benefit was that students could follow along with the professor, drawing the same thing on their own tablet that he was drawing on his. A few other reasons were given, mainly pertaining to increased visibility. A few suggestions for improvement were given, the most interesting being that students would like the professor to post the drawings online. This poses a slight issue since, while it is simple enough for the professor just to post online his newly annotated lecture slides in their entirety, or even just selected slides, it begs the question as to whether there is a better way for snippets of annotation to be shared in either a one-to-one or one-to-many environment. Various conferencing software packages have been designed to tackle this sort of issue, but since we are using, and will continue to use, Windows Journal, having students download Journal format slides with new annotations is the best approach, one that students seem, in any case, willing to go along with.

Conclusions

In summary, our interviews revealed a variety of useful information—students used their tablets to take notes for virtually every day of 9.01/9.14, but on the occasions when they did not, it was usually due to a technical problem such as wireless connectivity issues or another more easily corrected issue such as the professor not posting the slides to Stellar early enough. Students used the tablets in their other classes and in a variety of subjects but were much more likely to use the tablets when electronic versions of the lecture slides were already available online, necessarily before lecture. Of great importance is the fact that students, with no encouragement from us, asked their Professors to post lecture slides early and that these Professors agreed in each case.

Some students had difficulty using the tablets in subjects which required highly detailed note-taking, such as Molecular Chemistry. Students generally cited both the pros and cons of tablets already described in chapters 2 and 6. There was generally only a slight delay at the beginning of lecture before students were ready to take notes, one that did not seem to concern students overmuch. Student use of software consisted of an unsurprising mixture of Windows Journal, web browsing, office applications, and entertainment applications. As predicted, students without exception have an organizational system on the tablet which generally groups material first by course and then by type of file with each course, and generally places all the course-level folders in an obvious place such as *My Documents*.

Overwhelmingly, the primary change in students' note-taking behavior is their added use of color pens for a host of purposes. Most students do go back and modify their notes after the day on which they were first taken. Most students do not have a study group but those that do use the tablets in their study groups. All students think we should continue using tablets in 9.01/9.14 in the future, though a total of five students were hesitant, primarily because they weren't sure tablets were any better than paper. Tablets seemed to quickly displace students' use of laptops, mainly because the tablets are so much more portable, though many students said they would have used the tablet for even more tasks if they'd had it for longer than a semester. Finally, students do benefit from having the professor use a tablet as a lecture presentation device.

Overall, despite a few problems which primarily consist of inconsistent wireless network behavior and limitations of the digitizer that prevent extremely detailed note-taking, student opinion of the initial stages of our Paperless Classroom project can only be said to be high.

8.2.6 Professor Interviews

Brief interviews were conducted with two MIT professors regarding their use of the Tablet PC in teaching. The first, Professor Gerald Schneider, is a rapid adopter of new technologies in the classroom. However, it is not his policy to adopt technology for the sake of adopting technology—there must be grounds to believe that the use of a particular technology will increase learning. Professor Schneider uses a tablet to teach 9.01 and 9.14, the subjects under consideration in this thesis. He uses the tablet to present his PowerPoint presentations, first converting them into the Windows Journal format so he can annotate his lecture slides during class. As was shown in section 8.2.5, students find this use of the tablet to be helpful, largely because it allows them to follow along and "be on the same page" as the professor, drawing diagrams as he draws them. Some students also note that it is easier to see the professor pointing to things with the tablet than it is when he uses a laser pointer. While still adapting to the need to post materials slightly before class begins, Professor Schneider feels there is virtually no time investment required to teach with the tablet, and to have students learning using tablets, and that the only reason it might cost him a little extra time is because he still has to manage the distribution of paper-based content. If paper were eliminated from use in his classes, he would at least break even on time, and there would be, he believes, significant benefits for the students.

Professor Julian Wheatley is an expert in East Asia and is currently teaching Mandarin Chinese courses at MIT. He is somewhat less comfortable with new technology than Professor Schneider—not uncomfortable in terms of his willingness to try new technologies, but simply in terms of his skill level with computers, and Windows-based computers specifically. He uses the tablet in his Chinese courses with an overhead projector to increase legibility of his presentations. He uses the tablet to demonstrate the drawing of Chinese characters as well as to give slide shows of various Chinese places. He believes that, in the hands of students, the Tablet PC can be a truly valuable foreign language learning tool—essentially an entire language lab wrapped into a highly portable device. The critical feature of the Tablet PC that separates it from the rest of the crowd is, of course, the fact that it allows you to write directly on the screen using a stylus. This is important because students learn Chinese characters more easily if they write them by hand—simply using a word processor does not require the student to actively recall the components of each character. The Tablet PC is an excellent tool for doing Chinese homework: Professor Wheatley already distributes homework assignments using Stellar, so the next step is for him to post Journal format versions of his homework to Stellar so students with tablets can download them and complete them directly on their tablets. Students would then simply send their completed homework back to the professor who would correct them directly on his tablet, sending the corrected versions back to each student. This would reduce homework turnaround substantially, giving students more immediate feedback which translates into increased learning—students may not remember what they did on their homework three weeks afterwards, and the instructor's comments are significantly less instructive by that point. In any event, Professor Wheatley is looking forward to the coming semester and intends to carry out the experiment: six students will receive tablets for use in Chinese class during the Spring 2004 term.

8.2.7 Note-taking Data

Although students were asked during interviews about their note-taking habits while using the tablet, a direct examination of students' notes (which they provided us with at the end of the term) proved to be instructive. While we performed no formal analysis of the ways in which students use tablets to take notes or the ways in which students' note-taking might have changed as a result of having a tablet, we did go through all student notes from both semesters in order to find interesting phenomena. As a consequence of performing this scan of students' notes, it was possible to draw a number of informal conclusions:

- Students varied significantly in the quantity of notes taken, but generally took notes on at least half of the slides in a lecture
- Students varied significantly in terms of their use of the highlighter—some seldom used it, some used it on virtually every slide
- Virtually all students at least occasionally used multiple colors to make their notes more legible or to encode special information pertinent to a given slide
- Generally speaking, when there was no special need for multiple colors, students used a single color for their textual notes
- Diagrams drawn by students were much more likely to contain multiple colors than plain text
- There was evidence of multiple students creating similar diagrams, presumably because the instructor was drawing the same diagram on his tablet during lecture
- Several students (the minority) used the keyboard to write text and the stylus to create diagrams or additional text on the same slide
- Students also did some things that are basically impossible on paper, such as writing directly over dark backgrounds and producing legible text

The variation in quantity of notes and varying use of the highlighter is evident from looking at figures B-39 through B-41 which contrast three different students' overall note-taking styles. Figures B-39 and B-41 also demonstrate the students' tendency to use the same color when merely taking textual (that is, non-diagrammatical) notes. Examples of students using color to convey additional information are given in figures B-42 through B-44. In each of these three figures, students used color to match sections (or pathways) of the brain with descriptive text written in the same color as the region it describes. This was not, however, the only way students used color and each of the uses for color students cited in section 8.2.5 were observable in their notes.

Another observation which agreed with students' interview statements relates to the topic of section 8.2.5. As stated in that section, some students mentioned creating diagrams on their tablets along with the professor during lecture. This is evidenced by what would otherwise be suspiciously similar diagrams in different student's notes, as shown in figures B-45 and B-46 as well as figures B-47 and B-48.

The interesting phenomenon in which some students made simultaneous use of a keyboard and stylus during note-taking is shown in figure B-49. While several students' notes contained similar examples of this technique, the majority of students exclusively used the stylus during note-taking. However, I was fortunate enough to observe several students making simultaneous use of the keyboard and stylus during lecture and while this was a means of using the tablet we had not anticipated, it does make sense in retrospect. Most students simply tilted the screen back until it was flush with their desktop (or lap) and made alternate use of the pen and keyboard as they saw fit. However, I noticed one or two students who left the screen at near right-angle to the keyboard (the way a laptop would normally be) and were still able to comfortably write on the screen.

Figures B-50 through B-52 demonstrate one of the ways in which tablets allow note-taking in ways not possible on paper. In these cases, students have written directly over diagrams or dark backgrounds in ways that would likely be illegible had they been written on a printed version of the lecture slides in question. The last of these three figures is somewhat amusing but, assuming that my interpretation is correct, it conveys an important point—the student who produced the notes in that figure seems to have written the word "wow" on this lecture slide because her ink showed up so well against the dark background and she realized that it would not have been possible on regular paper.

8.2.8 Retention Surveys

During the Fall 2003 semester, a group of students at MIT approached us stating their interest in performing a small study of the Paperless Classroom as part of their final group project for a class. I met informally with these students to discuss their ideas for the project, but my involvement was fairly minor and the project design was ultimately of their choosing. They were kind enough to allow me to include their findings in this thesis since they were relevant to the topic being discussed.

The project they decided on consisted of a series of surveys and quizzes given to all students in 9.01 which aimed to determine whether the tablets had any impact on students' retention of material immediately after a given lecture. In order to make this determination, two types of surveys were distributed. First, a one-time survey was distributed which asked questions which aimed to determine students' motivations for requesting or not requesting a tablet as well as some demographic information (e.g. students' cumulative GPA). The second type of survey was offered on three occasions just after lecture and contained five questions each time—three quiz questions drawn from material taught in that day's lecture, one question asking students about their stress level, and one question asking students how much of that day's lecture material they thought they retained.

Demographic Survey

I will now provide further detail regarding these questions and the findings they produced, starting with the demographic questions. The questions asked in the demographic survey are shown below, with all questions on a scale from 1 to 5, 1 being lowest, 5 being highest.

- Please characterize your familiarity with computers (1 = minimal experience 5 = extensive experience)
- Please characterize your interest in 9.01 (1 = completely uninterested 5 = extremely interested)

- How interesting / engaging do you find the 9.01 lectures to be? (1 = boring 5 = fascinating)
- Please indicate your cumulative GPA range (0-2.0, 2.0-2.5, 2.5-3.0, 3.0-3.5, 3.5-4.0, 4.0-4.5, 4.5-5.0)
- Consider all classes you have taken at MIT: On average, approximately what percentage of lecture material do you retain (remember and understand) at the end of a lecture? (normalized to a maximum of 5 for use in the graph)

Students' responses to each of these questions are shown, in order, in figure B-53. As noted above, all responses were on a five-point scale with the exception of the last question which was normalized to a five-point scale for purposes of creating the graph. Inspection of the graph reveals that, overall, students state that they are fairly familiar with computers (with a mean response of 3.50 out of 5) and are quite interested in 9.01 in general (with a mean response of 3.96 out of 5), though their interest in 9.01 lectures specifically is somewhat lower at 2.73 out of 5. Students' average overall GPA is a B average (3.96 out of 5 to be exact), and their average (self-reported) retention of all material in all of their lectures is 57

The only significant difference between any of the three groups, as determined by pairwise two-tailed t-test, is that tablet users ($\bar{x} = 4.21, s = 0.54$) had a significantly higher general interest in 9.01 than did non-volunteers ($\bar{x} = 3.70, s = 0.93$) with $p = 0.038$. A related, though not identical, finding was described in section 8.2.3—it was noted in that section that tablet users enjoyed their in-class and out-of-class experience significantly more than did volunteers without tablets. The fact that tablet users have a greater interest may be related to their greater enjoyment of the class, though no causal relationship can be established using these findings alone.

Motivations for Requesting a Tablet

I will now discuss the data and results associated with the survey which determined students' motivations for requesting, or not requesting, a tablet. Regardless of whether or not they actually requested a tablet, students were asked to rank, from

1 to 7, the degree of influence seven potential sources of motivation had on their decision as to whether or not to request a tablet:

- Interest in new technology
- Willingness to try new learning strategies
- Interest in improving academic performance
- Willingness to accept associated responsibilities
- Dispreference for using paper
- General willingness to try new things
- Interest in electronically organizing course materials

Students were also asked to rank, from 1 to 7, each of the above factors in terms of how much they dissuaded them from requesting a tablet, regardless of whether or not they ended up requesting one. That is, students were asked to rank the influence of the following factors:

- Disinterest in new technology
- Unwillingness to try new learning strategies
- Disinterest in improving academic performance
- Unwillingness to accept associated responsibilities
- Preference for using paper
- General unwillingness to try new things
- Disinterest in electronically organizing course materials

As it would turn out, the same information could probably have been obtained using a simpler and less confusing measurement technique. Additionally, the rank scale essentially discards information because while it may determine the order in which the seven factors motivated students to request a tablet, it tells us nothing about the magnitude of the influence—for example, a student could have been slightly and equally motivated by each of the seven factors and would have still been forced to indicate a ranking on the survey. Another student might have been solely motivated by a single factor and negatively motivated by the remaining factors and still have produced the same survey results as the first student. However, there are still some conclusions to be made by looking at the results, given in figures B-54 and B-55, which provide rankings of motivations for requesting and not requesting a tablet respectively. Recall that, since this is a rank scale, numerically lower answers indicate a higher degree of motivation.

Perhaps the best way to interpret the overall results is by looking at the most influential factors that persuaded or dissuaded students from requesting tablets. Figure B-54 indicates that the most significant factors that motivated students to request tablets were interest in trying new technology, interest in trying new things (in general), and interest in electronically organizing course materials. Figure B-54 shows that the two most influential factors that dissuaded students from requesting a tablet were unwillingness to accept the responsibilities associated with having a tablet and a preference for using paper, rather than tablets, to take notes. The latter of these two agrees with a finding described in section 8.2.5 which showed that, of the few students who had hesitations about using tablets in the future, the largest source of hesitation was simply that tablets might not be any better than paper.

There were several significant differences between volunteers and non-volunteers in terms of these motivations. Before considering these, it is important to note that, as mentioned earlier, the rank scale introduces complications in interpretation of the results. For example, those who volunteered may have been more motivated by every single factor than the non-volunteers, but the differing relative order of motivations within each group might result in the appearance that non-volunteers were more motivated by a particular factor because they ranked it higher. In any case, it would have been more instructive to have known the extent to which the actual magnitude of motivations differed between the volunteer and non-volunteer groups. Unfortunately, this magnitude was not measured, so only the difference in rankings will be discussed.

The significant differences between volunteers and non-volunteers in terms of their motivations for requesting or not requesting a tablet will now be described. Recall that since this is a rank scale (from 1 to 7), lower scores indicate a higher degree of motivation. Volunteers ($\bar{x} = 1.91, s = 1.33$), more so than non-volunteers ($\bar{x} = 3.52, s = 2.27$) were motivated to volunteer for a tablet because of their interest in new technology ($p = 0.003$). Volunteers ($\bar{x} = 2.75, s = 1.22$) were also more motivated than non-volunteers ($\bar{x} = 3.65, s = 1.77$) by their general willingness to try new things ($p = 0.04$). Non-volunteers ($\bar{x} = 3.47, s = 2.07$), on the other hand, were more motivated than volunteers ($\bar{x} = 4.66, s = 1.77$) to volunteer because of their interest in improving academic performance (p=0.04). Non-volunteers ($\bar{x} = 5.00, s = 2.09$) were also more motivated than volunteers ($\bar{x} = 6.44, s = 1.13$) because of their willingness to accept associated responsibilities (p=0.003). Note, however, that in this last case, both groups, on average, listed this as their lowest motivation for volunteering and simply differed in how low they ranked this particular item, so it should not be interpreted as meaning that non-volunteers were particularly willing to accept the associated responsibilities—this reminds us once again of the potential of the rank scale to mislead.

Volunteers ($\bar{x} = 1.89, s = 1.57$) were more dissuaded from volunteering for a tablet than non-volunteers ($\bar{x} = 3.50, s = 2.44$) because of their unwillingness to accept the associated responsibilities (p=0.008). Finally, non-volunteers ($\bar{x} = 4.48, s = 2.02$) were more dissuaded from volunteering than were volunteers ($\bar{x} = 5.50, s = 1.50$) because of their lack of interest in trying in new technology (p=0.047).

Post-Lecture Retention Quizzes

Recall that the primary purpose of this particular student project was to determine whether students with tablets and those without tablets differed in their retention of material immediately after a lecture. To determine this, short quizzes were offered at the end of three 9.01 lectures, all in the last month of the semester, well after tablets had been distributed. To determine students' retention of material, the professor created three fill-in-the-blank questions that were relevant to material taught in that day's lecture. In addition to asking these three quiz questions, each quiz also asked students to specify their level of stress that day as well as their estimate as to the percentage of that day's lecture material they had retained. The results for each of the three quizzes were averaged for each student and are shown in figure B-56. As may be apparent from the graph, there were no significant differences between students with tablets, volunteers without tablets, or non-volunteers in terms of their scores on the quiz questions, their (self-reported) stress level, or their (self-reported) retention level.

Conclusions

Thus the data from these retention surveys provided some interesting findings. Tablet users were more interested in 9.01 than those who did not volunteer for a tablet, though whether this was due to their having a tablet or was instead somehow linked to the underlying reasons for their requesting a tablet is not clear. Volunteers can be differentiated from non-volunteers on the basis of their interest in new technology, their general willingness to try new things, their relative disinterest in improving academic performance and their relative unwillingness to accept the responsibilities associated with having a tablet. These results regarding motivation must, however, be interpreted carefully since a rank scale was used in measuring students' motivations for requesting tablets. The main purpose of the surveys, to determine whether students with tablets retained a different amount of material, yielded no significant results, though the lack of differences between groups could be considered a result in itself—tablets do not have a positive or adverse impact on students' retention of material. However, since only three quizzes were offered with three short questions each, the sample is arguably too small and a more in-depth study may be warranted.

8.2.9 Tracking Software

During the Fall 2003 term only, all students with tablets, as one of the terms of their receiving a tablet, allowed a usage tracking software to be installed on their tablets. There were, in fact, three pieces of software used to determine the type and frequency of students' tablet usage—a study program called *flashCube*, a program called *swClient* which produced a popup window at regular intervals to determine what students were working on and when, and a piece of commercial software called *Codename Alvin* which kept a log of all applications students used and when.

flashCube

flashCube is a piece of software which I wrote several years prior to its use in this project which is basically a study program that allows the user to study terms and concepts relevant to their coursework using an interface which resembles that provided by flash cards. Figure B-57 shows the screen a 9.01 student might see while studying vocabulary. flashCube also contains a number of additional useful features, such as a dictionary search function which allows the user to search for a specified keyword and see a list of entries containing that keyword, as shown in figure B-58. flashCube provides a simple interface for the creation of content to be studied, so it was a useful tool for general student use in 9.01 and 9.14 both of which depend heavily on a specialized set of vocabulary—vocabulary which can be reviewed using flashCube. Thanks to the fact that the 9.01/9.14 Professor produced an extensive set of vocabulary and associated definitions for flashCube, it was a popular tool for 9.01/9.14 students, those with and without tablets alike.

In order to gain some insight into the time and frequency of students' studying, I installed a tracking mechanism in flashCube which kept track of all vocabulary items a given user studied, keeping a millisecond-accurate time stamp as well as the course number (e.g. 9.01) and lesson number (e.g. Lesson 4, the Visual System) associated with each vocabulary item viewed. These usage data were sent via network, along with the student ID of the user, to a server which collected the data in real time and stored it for later analysis. While disconnected from the network, flashCube automatically stored its usage data locally until a network connection was detected, at which time it sent all usage data to our server. This prevented students from having to manually provide us with their usage data which had proven to be a problem in the past.[7] While the flashCube data contained a number of interesting findings, I will focus mainly on the total number of vocabulary items a student viewed. It is not known to what extent this total usage is indicative of other factors, such as total amount of studying or the total amount of studying using the tablet, but the results will still be informative even if their implications are not known.

The overall usage, as determined by the total number of vocabulary items viewed during the entire semester, is indicated in figure B-59. Note that this does not mean that each vocabulary item viewed was unique—for example, a student might review all vocabulary from lesson 2 on a given occasion, and then review it all again later, both these sessions would add to their total usage. As usual, students are broken into three categories—those with tablets, those who volunteered for a tablet but did not receive one, and those who did not volunteer.

Despite a huge variation in usage among students (which results in a large standard error), there were significant differences found using pairwise two-tailed t-tests between the three groups—namely that tablet users ($\bar{x} = 418, s = 688$) used flashCube significantly more than both volunteers without tablets ($\bar{x} = 97, s = 280$) alone, and all students without tablets taken collectively ($\bar{x} = 168, s = 351$), with $p = 0.041$ and $p = 0.015$ respectively.

This difference in usage existed despite the fact that all students were provided equal access to flashCube—not only could students without tablets download the software but the software was already installed on Athena, the public computing system at MIT, meaning that students wishing to use flashCube over Athena did not even have to install it to use it. Although I helped a few students with tablets with

[7]flashCube had been used in other educational experiments outside the Paperless Classroom and at one point students had to manually provide us with the file containing their usage data. Far too many students forgot to save their file at the end of the semester and deleted it, resulting in loss of data. This was the original motivation for my creating the server-based system used in the Paperless Classroom.

the flashCube installation process, the only thing I did for every tablet user was to download the installation file for them along with all the other software I preloaded. I did not even install flashCube on the tablets, so it is fairly safe to say that I was not responsible for the difference in usages. Rather, the tablets themselves likely made access to flashCube much easier, as predicted by the notion of *Ubiquity of Access* as described in section 2.3. However, it is possible that tablet users used flashCube more because of a number of other reasons—they may, for example, study harder in general than other students—but the fact that they used flashCube more than the control group (that is, volunteers without tablets) means that, regardless of the underlying cause, tablets did result in additional flashCube use.

swClient

While flashCube gave data concerning the usage of a specific program, we thought it would be interesting to find out how much students use their tablets regardless of the application. In order to accomplish this, I wrote a small application, shown in figure B-60 which behaved in the following manner—once the tablet user logged in, *swClient* would keep itself hidden for a 5 minute grace period so as not to irritate the user right away. Then, it would make itself visible, and ask the user to specify their current activity. A preset list of activities is provided via a user-editable text file, and I had students provide me with a list of courses they were taking so I could type those courses into the text file, using them as the list of possible activities.

In addition to the students' courses, I also added an activity called *Personal* which was simply to entail everything not related to schoolwork for a particular course, though an additional *Other* field allowed the user to type in a name for their activity. The student would then have to click the button which most closely described what they were currently doing. If students tried to dismiss or close the window, it would become invisible for 30 seconds and then reappear. Once a student specified their activity, the program remained hidden for 20 minutes after which it would reappear. This software ran on students' machines continuously, even if they restarted their machine.[8]

As we did not consider using a program such as this until partway through the term, it was not available until the second half of the semester. Also, since students were not all available on the same day to have the software installed, the time of installation varied from student to student. However, I account for this when performing data analysis. The raw data consist of a series of millisecond-accurate timestamps and the activity a given student was performing at that time, along with the student's ID. These data are automatically sent from the students' tablets using the same server-based mechanism installed in flashCube as described in section 8.2.9.

In order to make use of this data, I collected all of the data from the server after students had returned their tablets, and wrote a script which counted the total number of timestamps sent for each student. Since students had the software installed at different times, I took the last timestamp found for a given student minus the first timestamp, giving me a good estimate of the total amount of time they had swClient installed. I then divided the total number of timestamps by that interval, yielding a good estimate of usage frequency. Determining the exact amount of time a student spent using the tablet from this data is difficult, but a rough estimate can be found by multiplying the number of timestamps by 20 minutes, since the sampling period is 20 minutes.

One shortcoming of my software design, in retrospect, is that it does not sample at completely regular intervals since it waits 5 minutes upon startup to first appear and then appears every 20 minutes thereafter while still allowing the user to ignore it should they choose to do so. A better approach would have been to have the software simply appear on the hour, 20 minutes after the hour, and 40 minutes after the hour every hour to provide a regular sampling frequency. However, the aforementioned method of multiplying the number of samples by 20 minutes is roughly correct, though it probably provides a slight overestimate of usage because of the initial 5 minute interval—a student who waited for the program to appear, told it their activity, rebooted or logged out and logged back in, and then repeated the process could

[8]During installation, the software was set to run at boot time in the Windows Registry.

generate samples at the rate of $5 + x$ per minute where x is the time required to reboot or log out and log back in.

In any event, since only students with tablets were using swClient, no direct comparison between tablet users and other students is possible. However, it is interesting to see a rough estimate of students' usages, and this is provided in figure B-61. Usage is given as average hours per day of total usage (as determined by the method described above) and 9.01-specific usage for each student. As can be seen from the graph, there is significant variation in student usage, with an average of 1.85 hours of total usage per day, and an average of 0.71 hours of usage specifically for 9.01 each day. For reference, a student who used the tablet solely in 9.01 lectures would average 0.43 hours per day because there are three hours of lecture per week.

The chart also indicates that there is no particular correspondence between total usage and usage for 9.01. In fact, those students who used the tablets the most did not use the tablet for 9.01 any more than those who used the tablet much less. This would seem to indicate that 9.01 usage is fairly static among students[9] and that students who used the tablet more frequently were using it more frequently because they used it for a wider variety of tasks or classes. This allows us to divide our students with tablets into two types—those that mainly use the tablet for 9.01 because that was the "purpose" of the tablet when it was given to them, and those that took advantage of the opportunity to use the tablet for all tasks it was reasonably suited for. Students in the former category, roughly corresponding to students 11 through 22 on the graph constitute about half of the students that were given tablets. This brings up one last statistic that may be of interest—students spent an average of 58% of their time on the tablets for 9.01-related work, with a standard deviation of 29%. This certainly indicates that students were not using the tablets nearly as much in their other classes as they were in 9.01 since students at MIT generally take at least four classes each term.

The fact that the student with the lowest average usage had basically perfect attendance but averaged 0.23 hours per day, less than the 0.43 hour minimum estimate,

[9]But not completely static—usage for 9.01 ranged from 0.23 to 1.38 hours per day.

brings up an important issue regarding this data.[10] Namely, there is one reason why this data may not be completely accurate—despite the fact that swClient was designed to be as unobtrusive as possible, it nonetheless did pop up a window every 20 minutes, and some students may not have liked this. While the program persisted in popping up even if the window was minimized or closed, it was possible to kill the process using the *Task Manager* built into Tablet XP (the Task Manager is most easily opened by hitting CONTROL-ALT-DELETE), and at least some of the students probably knew how to do this. Doing so would prevent the software from running until the next time the student logged out or rebooted. Especially knowledgeable students might even have known how to remove the registry entry responsible for the launch of the program at startup, but at that point an even lower-tech approach would have worked—simply deleting or moving the program directory would prevent it from running, given that the process had been killed first.

However, since I checked each of the returned tablets for the swClient directory and each of them was intact, a student using this approach would have to have moved the program folder back to its original location before returning the tablet, something which seems unlikely. My assumption is therefore that none of the students actually removed the software but that at least some of them killed the process at least on some occasions. If this is indeed the case, then the usage data just described are actually an under representation of usage. Therefore, the data presented can be considered a lower bound on the actual usage, provided that the aforementioned act of multiplying the number of timestamps by 20 minutes to determine total usage time is valid.

Codename Alvin

The third and final piece of software we used to track students' usage was a commercial program called *Codename Alvin*. This program kept track of the name of each application opened and closed by the user, and provided a timestamp along with each of these events. Unfortunately, while this software seemed to work well on the

[10] This student, in fact, handed in the tablet before finals week began, and thus not even the fact that there are no 9.01 lectures during finals week can account for this discrepancy.

machines we tested it on, it exhibited undesirable behavior on students' machines which primarily consisted of its slowing the tablets down, especially during certain important operations such as saving a Journal file which had been modified. This slowdown was undoubtedly related to the fact that the process was listed as using 100% of the CPU in the Task Manager. So we quickly removed it from all of tablets and limited data was obtained as a result. This program's failure to work properly may have been related to the fact that it was extremely inexpensive—$15 per license. Many other programs were available costing upwards of $50 per license, and while we originally thought this was too expensive, it may have been worth it had the software provided usable data for an entire semester.

8.2.10 Correlation Data

As a final means of extracting interesting findings from the wealth of data collected during the Spring and Fall 2003 terms, I performed a cross-correlation between all measures which produced numerical results. This was done independently for each of the two semesters' data. Then, using the appropriate numbers of degrees of freedom for each pairwise comparison, I performed significance testing on each of these correlations. The result was two large matrices—one containing correlation coefficients for each pairwise correlation between all measures, one containing the significance level corresponding to each of the entries in the first matrix.

I then wrote a small program which took a correlation threshold and significance level threshold as arguments and parsed these matrices, producing as output a file containing a set of nodes and edges which constituted a graph. The nodes in this graph represent specific measures, such as a students' final exam scores, or their responses to each survey question, and the edges connecting a pair of nodes signify the existence of a significant correlation (as specified by the input arguments) between two nodes, i.e. between two measures. The output file format was the format used by *dot*, one program belonging to Bell Labs' *Graphviz* family of graph-producing software.[11]

Using the resulting file as input to the *dot* Graphviz software, I was able to pro-

[11]See http://www.research.att.com/sw/tools/graphviz/

duce graphical representations of the correlations. Smaller, more readable, graphs were producible by using stricter requirements for the correlation coefficient and significance level used in the graphs, but loosening the restrictions on these values produced graphs showing a larger variety of correlative effects. I will now describe these correlation data and their implications for each of the two semesters in turn.

The correlations found can be broken down into three categories, those which are:

Type I Correlated a priori because one measure is mathematically derived from the other[12]

Type II Correlated because although they are separate measures, they measure near-identical things

Type III Unexpected correlation, or at least one between nontrivially different measures

Examples of each of these types will be given as part of the analysis itself and the distinction between them should become clear. Also note that my labeling of these correlations with one of the types is subjective, but should seem reasonable in each case. The first two types of correlations serve to validate the data because they are expected to exist for mathematical and logical reasons respectively. The third type of correlation may constitute a novel discovery and in any case tends to be the most interesting simply because, by definition, it relates two significantly different measures. Also note that the correlated data form not only pairs, but clusters, sometimes nearly fully connected ones, consisting of multiple mutually correlated measures. These clusters in nearly every case consist of a number of measures that measure similar or identical things. The node names are shortened in many cases to make the graph more compact, so it may be useful to refer to table A.7 which maps node names to the measures they represent. Also note that the nodes are color coded by type:

[12]Technically speaking, only a linear relationship between two variables can be detected by use of correlation, so *mathematically derived* in this case assumes a relationship that is at least somewhat linear.

Dark Blue Beginning-of-term survey questions

Light Blue End-of-term survey questions

Yellow LAQ questions

Gold LAQ Meta-questions—mastery, performance-approach, performance-avoidance, intrinsic motivation, graded performance

Red Grade-related measures (e.g. midterm score)

Pink Retention survey motivation and demographic questions (with the exception of self-reported cumulative GPA which was colored red so as to be grouped with the other grade-related measures)

Brown Retention survey daily questions—quiz score, stress level, self-reported retention

Orange Tracking software data—swClient and flashCube

Note that there were other types of data used in the cross-correlation that did not show up in any of the graphs because they produced no significant correlations. Among these is the CSA data, with WA and VI ratios treated as separate measures. (The CSA was described in section 8.2.2.)

Two graphs were created for each semester, one which is more restrictive of the correlation coefficient and significance level required for a correlation to be shown in the graph, and one which is less restrictive of these values. The former graph is smaller and easier to read, but the latter graph depicts a greater number and variety of results. Thus, we will consider each in turn. Note that the correlation thresholds specified for a graph hold for each effect described in association with that graph, and in cases where the correlation coefficient and significance level are not explicitly mentioned, a lower bound on these values can still be inferred by virtue of their appearing in the graph in the first place.

First, it is important to note that a correlation between two measures does not imply causation between the two measures. Even if there is a causative relationship between two measures, the correlation can not predict the directionality of that causation. Care must therefore be taken in interpreting these results and while I may seek an explanation for each correlation, and may posit a particular causative relationship between them, I do not mean to imply that such findings are conclusive.

Spring 2003

The small graph for the Spring 2003 term of 9.14 is given in figure B-62. In this graph, all correlations have $|r| \geq 0.65$ as well as $p < 0.001$. Correlations with $|r| \geq 0.9$ are depicted as a bold edge connecting two nodes. There are no negative correlations in this particular graph, but had there been, they would have been represented by a red edge connecting the two negatively correlated nodes. The larger graph is given in figure B-63. All edges in this graph have $|r| \geq 0.5$ as well as $p < 0.01$. Dashed edges represent those correlations for which $0.65 > |r| \geq 0.5$, solid edges represent those for which $0.8 > |r| \geq 0.65$, and bold edges represent those for which $|r| \geq 0.8$.[13]

Every edge in these graphs essentially represents a significant relationship, but since the majority are Type I or Type II relationships, a relatively small fraction represent potential findings of interest. I will now review each correlation in the graph, sometimes considering an entire cluster of correlations at once. Since each of these effects described below have $r > 0.65$, it will only be necessary to refer to the smaller graph. The larger graph is merely provided for those who are interested in studying correlations on their own.

Effect #1, Type II/III This effect relates questions 8 and 9 from the beginning-of-term survey. These questions are *Would a tablet help you to better organize materials and handouts for 9.14?* and *Would a tablet help you to organize your own notes for 9.14?* respectively. Students' answers to these questions were correlated with $r = 0.96$ and $p < 0.0001$. The connection between these is quite apparent but they

[13]The range of values of r corresponding to dashed, solid, and bold lines is intentionally varied from figure to figure to maximize the amount of information conveyed about the correlation values within each figure while minimizing the use of dashed lines which clutter the graph if too many exist. Edges in the graph could also have been labeled with the actual correlation values, but this produced significantly more cluttered graphs.

are distinct questions and that is the justification for labeling this a Type II/III correlation. From this we can conclude that the tablets' ability to organize materials and handouts entails its ability to organize notes and vice versa, as we might expect. Recall that the fact that this is an expected correlation does not make it a useless one—this, and all subsequent expected correlations serve to validate the data from the measures they correlate.

Effect #2 , Type II/III This effect relates questions 11 and 12 from the end-of-term survey. These questions are *Are you currently successful at organizing materials and handouts for 9.14?* and *Are you currently successful at organizing your own notes for 9.14?* respectively, with $r = 0.91$ and $p < 0.0001$. In parallel with Effect #1, this shows that success at organizing materials and handouts goes hand in hand with success at organizing notes. This constitutes another unsurprising but data-validating finding.

Effect #3 , Type II The third effect relates LAQ questions 3, 8, 13, 18, 19, and 25. As noted in section 8.2.1, the LAQ contained a number of intentionally redundant questions which were nearly identical in meaning but used different wording. The point of that redundancy was to allow validation of the data, and that is exactly what this effect shows—the questions being correlated, while not quite identical, ask very similar things, and the fact that they are correlated so strongly suggests that the LAQ data are indeed accurate. The nodes are also shown connected to the *pAvoid* node, corresponding to the performance-avoidance measure. These nodes correlate with the performance-avoidance measure because the performance-avoidance measure is simply the average of each of these six LAQ questions. Furthermore, since intrinsic motivation is negatively related to performance-avoidance, the intrinsic motivation node has negative correlations with the performance-avoidance node as well as a number of the nodes corresponding the individual LAQ questions.

Effect #4 , Type II Another cluster consists of correlations between LAQ questions 2, 6, 9, 14, 15, and 22. While effect #3 consisted of the LAQ questions pertaining to performance-avoidance, this cluster corresponds to questions regarding performance-approach. The six nodes in this cluster are, in fact, the six questions used to calculate the performance-approach factor. Since this graph shows only very high correlations ($r > 0.65$), there is no connection between the *pApproach* node and the graded performance node (not shown). However, since the latter is derived from the former, they are correlated, but the correlation is not strong enough to appear in this particular graph.

Effect #5 , Type I Our first example of a Type I effect, this effect relates students' final exam score with their final letter grade in the course, with $r = 0.89$ and $p < 0.0001$. Since students' final exam scores are used in a mathematical formula to determine their final grade in the course, this is a Type I effect, i.e. one in which the correlation is directly caused by a mathematical relationship between two measures. Note that while the term *final letter grade* is used, it actually refers to a raw score which is converted to a letter grade using a table lookup, but the two are functionally equivalent. This effect is not terribly informative since it is virtually guaranteed to exist, but it verifies that students' grades were calculated correctly and did in fact take final exam score into account.

Effect #6 , Type II/III This effect is perhaps the most interesting thus far and is the first to relate items from different measure categories (as signified in the graph by an edge between two nodes of different color). It relates end-of-term survey question 15 which is *If you had to guess, what letter grade would you expect to get in 9.14?* with students' midterm grade, where $r = 0.86$ and $p < 0.0001$. This tells us that students, quite rightly, used their knowledge of their midterm score (they had already taken the midterm when answering this question since the survey was given at the end of the term) when estimating their final exam score, which is perhaps unsurprising. It is, however, potentially interesting because it tells us that students are aware of their level performance in the class. It also serves to validate students' survey responses.

Effect #7, Type III This cluster consists of LAQ questions 5, 7, 11, and 12, as well as the homework average (and the LAQ mastery node). The four LAQ questions are each questions related to the mastery goal. The fact that the remaining two mastery questions did not show up simply means that $r < 0.65$ for those questions. Had a lower correlation threshold been used for this graph, the mastery node would also have been connected to the intrinsic motivation node, since the latter is derived from the former. It is interesting to note that while homework assignments are not nearly as large a factor as midterm or final exam grade in final grade calculation (something students are aware of), they do require significant effort. One conclusion is therefore that students who have a high mastery score are more likely to do well on homework because, while the homework does not contribute as much to final grade calculation as other grade measures, a student who cares about mastering the material will work hard on it anyway. The homework assignments arguably gave students the most flexibility to perform research on Neuroscience topics and formulate well-thought out solutions to problems, thus explaining why those with a mastery goal would excel in this particular area. Of course, working hard on homework presumably increases a student's understanding of material which should translate into better test performance (thereby affecting final grades), however, as explained in section 8.2.1, students who engage in *mastery* behavior do not necessarily increase their grades.

Remaining effects As can be determined from inspection of the graphs, there are a number of additional correlations to be described. However, the most revealing of the highly significant effects are described above (as well as a few examples of unsurprising effects) and the remaining effects are each similar to one of those given above. Inspection of the larger graph in figure B-63 may reveal a number of additional interesting effects, but this is an exercise left for the reader since a more extensive analysis will be provided for the Fall 2003 correlation data which represent a larger sample size and corresponding significance level.

Fall 2003

As noted earlier, there are two graphs for the Fall 2003 data, one smaller graph which places more restrictions on the correlation coefficient and significance level required for an edge to be placed in the graph, and a larger one that is less restrictive but harder to read. We will begin by looking at the small graph, shown in figure B-65, which contains the first eleven effects, and then consider the larger graph, shown in figure B-66 which contains the remaining effects.

The small graph contains dashed edges for which $0.7 > |r| \geq 0.65$, solid edges for which $0.85 > |r| \geq 0.7$, and bold edges for which $0|r| \geq 0.85$. Also, $p < 0.001$ for all edges in the graph. As with the Spring 2003 graphs, negative correlations are represented by red edges, and nodes are color coded by the type of measure they represent. A list of these color codings was given in the previous section. Also recall that the mapping from node names to the actual measures they represent is given in table A.7.

Effect #1, Type I/II This is a cluster consisting of each of the three daily measurements of students' stress levels performed as part of the retention quizzes, as well as the mean of those three measures. In addition to the correlations between the independent daily stress levels and the mean itself, which is of course a Type I effect, there is a correlation between two of the daily means, suggesting that stress levels on a given day are an indicator of stress levels on a later day (in this case, a week later). This is not surprising, but serves to validate the data students provided in their retention quizzes. For each of the correlations in this cluster, $p < 0.001$ and $r > 0.7$.

Effects #2, #3, Type I These effects were similar to the first effect, but pertain to daily self-reported lecture retention and post-lecture retention quiz scores respectively. However, since there were no significant correlations between any of the measures themselves, that is, each correlation was between a daily survey question and the corresponding mean of all three survey responses, this is a purely Type I effect which does nothing other than to show that the mean and cross-correlations were calculated correctly. Such validation is, however, important and that is why these effects were mentioned.

Effect #4, Type II This effect consists of a negative correlation between students' responses to the motivation section of the retention surveys—the items in question being students *Interest in having a tablet because of willingness to accept associated responsibilities* and their Disinterest in having a tablet because of unwillingness to accept associated responsibilities, with $r = -0.796$ and $p < 0.001$. This is a Type II correlation because these were separate but highly related measures that, in fact, are logical opposites. It is thus reassuring that a strong negative correlation exists between them. A glance at the large graph reveals a number of effects just like this one—they each appear as pairs of pink nodes connected by a red line.

Effect #5, Type I/II/III This is a large cluster consisting of various grade-related measures (indicated by red nodes) with many correlations between them. The grade-related measures in this cluster consist of final grade in the course, cumulative GPA at MIT, paper mean (with and without "zeros" which count missed papers as a zero grade instead of omitting them from the mean calculation), quiz mean (with and without "zeros" for missed quizzes), attendance (based upon number of missed quizzes), midterm score, and final exam score. $p < 0.001$ and $r > 0.65$ for all correlations in this cluster.

Most of these correlations are unsurprising, either because they are Type I correlations (e.g. the various measures correlated with final grade in the course) or because they are Type II/III correlations in that they don't measure identical things, but can be expected to be correlated because students who perform well or poorly on the midterm, for example, also tend to perform similarly on the final exam, with some exceptions. The same could be said for the correlation between (self-reported) cumulative GPA and its correlation to other grade-related measures, though it is interesting for two reasons—first, this was a self-reported GPA, so the correlation with actual grade data validates students' claimed GPA, secondly, it indicates that performance in other classes is an indicator of performance in 9.01 which, while unsurprising, is one of the few findings that relate coursework outside 9.01 to the other measures used.

Also present in this cluster is a single outsider—post-survey question 15 which reads *If you had to guess, what letter grade would you expect to get in 9.01?* which correlates with several of the grade measures. This correlation merits attention because it agrees with the notion found in effect #6 of the Spring 2003 correlations, namely that students are aware of their performance on grade measures and therefore use that knowledge in predicting their final grade.

Effect #6, Type II This effect relates the end-of-term survey question 1 *Do you enjoy your in-class experience in 9.01?* with the retention survey question *How interesting / engaging do you find the 9.01 lectures to be?* with $p < 0.001$ and $r = 0.71$. These questions ask similar things and that explains the presence of the correlation. This result serves to validate the data, and is especially helpful in this case because the questions came from completely different surveys.

Effect #7, Type II/III Effect seven consists of a relation between end-of-term survey questions 8, 9, and 10, *Would a tablet help you to better organize materials and handouts for 9.01?* and *Would a tablet help you to organize your own notes for 9.01?*, and *Would a tablet help you organize your time better (in any way, not just for 9.01)?* respectively. These are each correlated with each other (though the edge between questions 8 and 10 is only present in the large graph), which makes sense given that they each measure organizational capabilities of the tablet. It is, however, interesting to know that students believe these organizational benefits go hand in hand. $p < 0.001$, $r > 0.64$ for all correlations in this cluster.

Effect #8, Type II/III Similar to the last effect, this effect relates different types of organization, namely questions 11 and 12 of the end-of-term survey which read *Are you currently successful at organizing materials and handouts for 9.01?* and *Are you currently successful at organizing your own notes for 9.01?* respectively, with

$p < 0.001$ and $r = 0.765$. The conclusion is also similar, except that it pertains to students' current organization rather than the potential of tablets to organize.

Effect #9, Type II/III This triplet of inter-correlated nodes (the edges not present in the small graph show up in the larger one) consists of LAQ questions 5, 11, and 12. The other LAQ nodes present, corresponding to questions 1 and 7, are only connected to the mastery node. Note the distinction between these cases—LAQ nodes which correlate amongst themselves verify the validity of the measure whereas LAQ nodes simply connected to the mastery node do not validate the data because the mastery score was formed from the average of the individual LAQ scores, thus the correlation is expected, a priori. Also connected to two of these nodes is the retention survey question which read *Please characterize your interest in 9.01 (1 = completely uninterested 5 = extremely interested).* That the question regarding students' general interest in 9.01 also correlates with these suggests an unsurprising link between interest in material and motivation to learn material.

Effect #10, Type I This represents another cluster of LAQ questions, in this case questions 2, 6, 15, and 22 (with question 14 only connected to the *pApproach* node). As expected, each of these questions is one of the performance-approach questions, the intercorrelations between the nodes confirms the validity of the data.

Effect #11, Type I LAQ questions 19 and 25 correlate and questions 3, 8, and 18 also appear, connected to the performance-avoidance node. Needless to say, these questions are all performance-avoidance questions and thus correlate with the performance-avoidance node. That node, in turn, correlates negatively with the intrinsic motivation node since it is used in calculating intrinsic motivation and contributes negatively in that calculation. For similar reasons, had a lower correlation threshold been used for this graph, we could also have expected to see the performance-avoidance node negatively correlated with the grade performance node.

Effects including $|r| \geq 0.4$ and $p < 0.001$ Effect twelve and all those that follow will be most easily seen by referring to the large graph in figure B-66 which contains correlations as low as $r = 0.4$ but still have $p < 0.001$. In most cases, these effects are interesting subclusters of larger clusters.

Effect #12, Type III This effect consists of end-of-term survey question 11, *Are you currently successful at organizing materials and handouts for 9.01?* correlated with the LAQ performance-approach questions. This is a novel result, and may suggest that motivation to outperform others results leads to a general heightening of effort which results, among other things, in students organizing materials and handouts better.

Effect #13, Type II/III This effect relates students' quiz mean without zeros (that is, that simply ignores missed quizzes instead of assigning them a grade of zero) to their mean score on the retention quiz questions, with $p < 0.001$ and $r = 0.433$. Since the retention quizzes measured students' retention of material on the day it was taught and the regular quizzes measure students' retention of material taught on days prior, this finding suggests that retention of material on a given day translates into better quiz performance later.

Effect #14, Type III In this effect, there exists a negative correlation between end-of-term survey question 15 *If you had to guess, what letter grade would you expect to get in 9.01?* and LAQ question 18, a performance-avoidance question, with $p < 0.001$ and $r = -0.492$. This further reinforces the findings of Spring 2003 effect #6 and Fall 2003 effect #5, namely that students tend to be aware of their own performance level (the LAQ and Post-Survey were both given towards the end of the term so students' attitudes when taking them should have been roughly the same) since the students answering the LAQ question in the affirmative are presumably concerned that they are not performing well.

Effect #15, Type III Not unlike the previous effect, this one relates a student's thoughts about their performance to their enjoyment of lecture. The correlation is between LAQ question 8, a performance-avoidance question, and end-of-term survey question 1, *Do you enjoy your in-class experience in 9.01?*, with $p < 0.001$ and $r = -0.492$, and since the correlation is negative, this suggests that students who worry about doing poorly don't enjoy their in-class experience, which is reasonable.

Effect #16, Type III This next effect relates the end-of-term survey question 1, *Do you enjoy your in-class experience in 9.01?* to both the retention survey question *How interesting / engaging do you find the 9.01 lectures to be?* with $r = 0.710$ as well as the mean self-reported retention of material (as part of the retention surveys, students were asked, on three occasions after lecture, what percentage of that day's material they thought they had retained) with $r = 0.518$ ($p < 0.001$ for both). These two correlations suggest that enjoyment of lecture is somehow linked both to an interest in lecture and retention of a particular lecture. The exact interplay of these three cannot be determined from this data alone, but one sensible theory is that it is interest which comes first and results in enjoyment and retention.

Effect #17, Type III This effect consists of a correlation between the mean self-reported retention level and disinterest in having a tablet because of lack of general interest in trying new things (from the motivation questions section of the retention surveys) with $p < 0.001$ and $r = 0.472$. Since the questions regarding motivations for volunteering for a tablet were measured on a rank scale, lower values indicate a higher degree of influence. Therefore, this should effectively be considered a negative correlation, and the graph has been altered to reflect this. That is, the higher a student's self-reported retention level, the less important their lack of interest in trying new things was in terms of dissuading them from volunteering for a tablet. To rephrase this in understandable terms by removing the part about the tablet—the more material students retain, the more interested they are in trying new things. This is one example of an effect whose implications are somewhat unclear. One possibility is that students with tablets are interested in trying new things and retain more, resulting in a correlation between the two measures. In other words, a third variable correlates with each of these measures and so they correlate with each other but there is no causal relationship between them.

Effect #18, Type III Fortunately, this effect is a bit more transparent that the last one—mean self-reported stress level correlates with end-of-term survey question 16, How many hours per week outside of class do you spend on 9.01? with $p < 0.001$ and $r = 0.488$. The first conclusion that comes to mind is that having to spend lots of time working on 9.01, perhaps because of difficultly with the material, induces stress in students.

Effect #19, Type III This effect consists of a cluster of mutually correlated measures, some of which were already encountered in effect #7. In addition to the end-of-term survey questions 8, 9, and 10 which were highly correlated in that effect, this effect, by virtue of its allowing weaker correlations, adds three additional questions to the cluster—questions 4, 5, and 6 which are *Regardless of your answer to (3), would having a tablet decrease the tedium in your studies in 9.01?*, *Regardless of your answer to (3), would having learning software customized for 9.01 decrease the tedium in your 9.01 studying?*, and *Would having the tablet improve your understanding of 9.01 material due to its ability to display all handouts in color (as opposed to black-and-white handouts)?* respectively. Recall that questions 8, 9, and 10 were *Would a tablet help you to better organize materials and handouts for 9.01?*, *Would a tablet help you to organize your own notes for 9.01?*, and *Would a tablet help you organize your time better (in any way, not just for 9.01)?* respectively. $p < 0.001$ and $r > 0.4$ for all correlations in this cluster. The existence of a correlation between these measures suggests that attitudes regarding the potential for a tablet (or learning software) to help a student are general and that overall attitudes towards, say, learning technologies influence attitudes regarding each specific domain of potential benefits. In other words, those who are optimistic about tablets and their benefits tend to be optimistic across the board.

Effect #20, Type III While all prior correlations were significant at the $p < 0.001$ level, there is one additional interesting effect (not shown on the graphs) at the $p < 0.01$ level, with $r = 0.773$. This is the correlation between tablet users' average time spent per day using their tablet (as determined by the *swClient* software as described in section 8.2.9) with their ranking of lack of interest in having a tablet because of disinterest in improving academic performance. As in effect #17, the latter measure is on a rank scale, so lower answers correspond to a higher degree of influence. Put simply, the more frequently tablet users used their tablets, the more their volunteering for a tablet was due to their desire to improve academic interest. One interpretation is that students who feel the need to improve academic performance attempt to do so by studying more, and some of this studying is done with the tablet.

Conclusions

This section described a means of extracting a wealth of additional information from a large dataset by performing a cross-correlation between all measures and selecting a subset of all possible correlations by placing restrictions on the significance level and correlation coefficient of correlations we were willing to consider. The resulting set of correlations was then converted to graphical form by representing a correlation between a pair of measures as an edge connecting two nodes which represent the measures themselves. This graphical form made it possible to compactly represent the significant correlational data while simultaneously providing a means of finding larger clusters of mutually correlated measures by simply looking at the graph, rather than requiring computational means of extracting such clusters from correlation data. The graphical approach, coupled with color coding of nodes by the type of measure they represent, proved useful in that it made the general nature of correlations between measures immediately apparent—most correlations were between different measures within the same measure type—a correlation between related questions from the LAQ, for example.

The correlations within a given measure type generally served to validate the data for the measure in question, while the less frequently occurring correlations between measures from different categories tended to provide non-trivial findings. Within these non-trivial findings, there were several common themes. Several correlational effects suggested that students are aware of their performance level in the class. Other effects suggested that a given student's attitudes regarding tablets, and perhaps learning technology in general, are consistent in that students with positive (or negative) feelings towards a particular aspect of tablets tend to have similar feelings towards other aspects of the tablet as well.

A number of effects consisted of correlations between students' interest in material, their enjoyment of material, their interest in learning material, and their retention of material. These effects, while not entirely unexpected, were important because they provided a statistical connection between quantities that are fairly difficult to measure, such as enjoyment and interest. Their correlation suggested that even survey questions regarding these abstract notions produced data that approximated the underlying quantity rather well.

The most unanticipated effects were also the weakest in terms of their correlation coefficient but may represent novel findings. These include a correlation between motivation to outperform peers and organization of materials, a correlation between extremely short term (same-day) retention and somewhat short term (on the order of one week) retention, a negative correlation between fear of performing poorly and enjoyment in class, and a correlation between self-reported stress level and time spent studying outside of class.

From these data it is clear that any correlational effect between tablet usage and other measures is relatively weak ($r < 0.4$) with the exception of the strong correlation ($r = 0.773$) between rate of tablet usage and interest in having a tablet because of a desire to improve academic performance. Most other correlations involving quantities which concerned tablets specifically concerned pairs of clusters of highly similar tablet-related questions and thus did not ultimately bring too much to bear on the question of tablets' effects on students. It is worth noting, however, that the only measure of students' tablet usage was produced by the *swClient* program which was not available until more than halfway through the term and was not installed on all students' tablets at the same time. Had this software been present on students' tablets at the beginning of the term, the data might have been a more accurate representation of actual tablet usage and additional correlations might have been found.

For example, there were no significant correlations between any tablet related measure and any grade related measure. For that matter, grade measures almost exclusively correlated amongst themselves, with a few relatively unsurprising exceptions. This is somewhat unfortunate because the impact of other factors on grade measures is, at least on a superficial level, the thing we would like to understand the most. Nonetheless, the correlational data proved time and time again to validate the data in each of the measures described in this chapter, and this likely represents the main contribution of the correlational analysis.

8.3 Conclusions

Thus, over the course of three semesters, a variety of assessments were performed. Some of these assessments were performed for each of the three semesters—these include the LAQ, CSA, as well as analysis of the standard grade data associated with each course. A matched survey was given at the beginning and of the Spring 2003 term of 9.14 as well as at the end of the Fall 2003 term of 9.01, and exit interviews were held with all students with tablets at the end of the Spring and Fall 2003 terms. The Fall 2003 term also saw the addition of a series of quizzes and surveys which determined students' retention of material, collected some demographic information on students, and determined their motivations for requesting or not requesting tablets. Data collection software was also installed on students' tablets for the first time in the Fall 2003 term. Finally, a correlational analysis of all data collected was performed for both the Spring and Fall 2003 terms.

The LAQ measured students' motivations for learning and served more to characterize the attitudes of students than it did to point out differences between students with tablets, students who volunteered for a tablet but did not get one, and students who did not volunteer for a tablet. In terms of overall student attitudes, most students stated that they were interested in learning as much as possible in 9.01/9.14 and were not concerned with performing well simply for the sake of their career plans. One significant finding was that tablet users less frequently worried about performing badly in 9.01/9.14 than volunteers without tablets. Since volunteers without tablets represent a valid control group, it is likely that the tablets were the cause of this difference between the groups. It is possible that tablet users gained confidence as a result of having a tablet, believing that it would confer benefits. It is also possible that the tablets actually improved their performance and that they were aware of this improvement and therefore less concerned about doing badly in the course.

The CSA measured students' learning style, that is, whether they learn better when presented with information in a wholistic versus analytic fashion, or a verbal versus visual fashion. The CSA assumes that an individual's learning style is innate and cannot be changed so, rather than trying to determine whether a student's CSA scores could be changed by having a tablet, we were trying to determine whether students with particular learning styles were more likely to volunteer for a tablet, have certain attitudes towards tablets, or have higher grades. While there was a fair amount of variation in the students' CSA scores, there were no significant differences found between groups on the basis of their CSA scores nor did the CSA scores correlate with any other measures. However, the fact that students with tablets do not differ significantly in their learning styles from other groups suggests that the tablets are suitable for students with various learning styles, as does the fact that there was significant variation in learning style within the group of students with tablets.

The significant results from the matched surveys reflected well upon the tablets. Multiple findings suggested that tablets increase organization of materials, handouts, and notes. Also, students' belief that tablets can help them organize materials, handouts, and notes, and reduce study tedium may be underlying motivational factors for their volunteering for a tablet. Finally, students who volunteer for tablets may be generally more receptive to technology used for purposes of learning.

There was little direct evidence supporting any effect of tablets on grade measures. However, figure B-38 suggests that there may be a difference between groups and that a larger sample is needed before the possibility that tablets affect grades is ruled out—tablet users during the Fall 2003 term, in fact, outperformed both other groups in every grade category albeit by an amount that was not statistically significant. It is also possible that there was an increase in grades due to tablets but that a ceiling effect reduced the strength of the effect. Also, it was found that tablet users were more intrinsically motivated as a result of having a tablet, specifically because they cared about mastering the material more than they cared about outperforming their peers. Unfortunately, it would turn out that the latter attribute is more likely to result in high grades than the former, and this may also explain why no significant grade effect was found. In any event, the goal of the Paperless Classroom was to remove paper while maintaining or increasing the performance of students, the grade data clearly show that this condition was met.

Our interviews revealed a number of findings—students used their tablets to take notes in almost every 9.01/9.14 lecture, and on those occasions when they did not, it was usually due to a technical issue such a problem connecting to the wireless network or human error such as the professor not posting the slides to Stellar early enough. Students used the tablets in their other classes and in a variety of subjects but were much more likely to use the tablets when electronic versions of the lecture slides were already available online, necessarily before lecture. We also found that some students asked professors from other courses to post lecture slides before class so they could use their tablets to take notes and that these Professors agreed to do so in each case. This suggests that for courses that already have electronic materials available, the transition to a paperless environment is easily performed and that Professors are willing to make the minor changes necessary to accommodate students with tablets.

The interviews also revealed that some students had difficulty using tablets in subjects which required highly detailed note-taking, such as Molecular Chemistry. There was generally only a slight delay at the beginning of lecture before students were ready to take notes, one that did not seem to affect students appreciably. Students generally used Windows Journal, web browsing, office applications, and entertainment applications on their tablet and virtually all students have an organizational system on the tablet which groups material by course and/or by type of material (e.g. handouts, lectures, etc), placing folders with course materials in an obvious place such as *My Documents*.

Overwhelmingly, the primary change in students' note-taking behavior is their added use of color pens for a host of purposes. Most students modify their notes after the day on which they were first taken and do not have a study group, but those that do use the tablets in their study groups. All students think we should continue using tablets in 9.01/9.14 in the future, though a few students were hesitant on the basis that they weren't sure tablets were any better than paper though they didn't think they were any worse. Tablets seemed to quickly displace students' use of laptops, mainly due to their portability, and many students said they would have used the tablets for even more tasks if they'd had it for longer than a semester. Students also stated that they benefit from having the professor use a tablet as a lecture presentation device.

The retention surveys showed that tablet users were more interested in 9.01 than those who did not volunteer for a tablet, though whether this was due to their having a tablet or was instead somehow linked to the underlying reasons for their requesting a tablet is not clear. Students who volunteered for a tablet (whether or not they actually got one), compared to non-volunteers, were more interested in new technology, more willing to try new things, less interested in improving academic performance, and less willing to accept the responsibilities associated with having a tablet[14], though the actual extent of each of these measures is not known because a rank scale was used. The main purpose of the surveys, to determine whether students with tablets retained a different amount of material, yielded no significant results but this may at least show the lack of any adverse impact on students' retention of material as a

[14]This last finding is, at first, counterintuitive. However, the surveys were distributed long after students had received their tablets. Therefore, their responses may have been more negative regarding tablet-related responsibilities.

result of having tablets. Since one concern often voiced regarding having tablets or laptops in students' hands during lecture is that they will play games, check email, or surf the web instead of paying attention, the lack of any difference between groups in terms of post-lecture retention is a relevant one.

Students with tablets used flashCube significantly more than both volunteers without tablets alone, and all students without tablets taken collectively. This is possibly because they had access to the tablet, and therefore flashCube, whenever and wherever they wanted. To whatever extent this is true, it should also suggest that students will have increased access to their notes and other schoolwork on the tablet. That, in turn, should afford them benefits in terms of overall performance in the course though, as noted earlier, no significant difference was found between tablet users' and other students' grades. Since the swClient tracking software was only installed on tablets, it could not be used to compare students with tablets to those without. Rather, it was used primarily in correlational analysis in an attempt to see if students with higher tablet usage rates had different attitudes or performed differently in the course. That ended up yielding only a single result, namely that tablet usage correlated with a student's interest in having a tablet because of a desire to improve academic performance which may be due to the fact that a student who wishes to improve their performance may study more, and may do so using the tablet. Data from swClient also showed that there is no particular correspondence between total tablet usage and usage for 9.01 specifically. Rather, those students who used the tablets the most did not use the tablet for 9.01 any more than those who used the tablet much less, indicating that students who used the tablet more frequently were using it more frequently because they used it for a wider variety of tasks or classes, not because they were using it more for 9.01.

Finally, the correlational analysis produced a host of significant correlations most of which were between items from the same assessment type which served to validate the data for the measure in question. In contrast, the correlations between measures from different categories provided more non-trivial findings including the fact that students are aware of their performance level in the class and the fact that if a given student is positive regarding one aspect of the tablets, then he is positive regarding all aspects of the tablet. A link was also established between students' interest in, enjoyment of, interest in learning, and retention of, course material. There was also a correlation between motivation to outperform peers and organization of materials, a correlation between extremely short term (same-day) retention and somewhat short term (on the order of one week) retention, a negative correlation between fear of performing poorly and enjoyment in class, and a correlation between self-reported stress level and time spent studying outside of class. With the exception of the aforementioned swClient correlation, no significant correlational relationship was found between tablet usage and other measures. Unfortunately, there were no significant correlations between any tablet related measure and any grade related measure. In the end, despite only providing a moderate number of real findings, the correlational data did an excellent job of validating the data from each of the other measures.

Chapter 9

Conclusions

The ultimate goal of the paperless classroom was to eliminate the use of paper in two undergraduate Neuroscience classes at MIT while maintaining or increasing the level of performance of the students, as primarily measured by grades. The motivations for removing paper included the potential for increased organization of students' course readings, handouts, and notes, increased total access to these materials due to the ease of access to materials and portability, increased amount of information conveyed to students by the use of color in handouts, increased flexibility in students' note-taking due to the use of color, and, given a well-planned and extensive implementation of the paperless classroom, a reduction in total cost for the university.

9.1 Review of Implementation

The Tablet PC was suggested as a candidate for paper replacement and the single largest competing technology, laptops, were deemed inadequate for use in the Paperless Classroom first and foremost because of their inability to mimic the behavior of paper, something which is assumed to be a critical requirement, but also because of secondary considerations such as portability and flexibility of the form factor. It was also shown that when Tablet PCs are compared to laptops of similar physical dimensions, the disparity in price between these two technologies is significantly smaller than would seem to be the case when ignoring physical dimensions. It was found, however, that Tablet PCs can be as much as $400 more than a similarly-equipped laptop of equal size. However, the fact that the Tablet PC provides the user with the ability to write directly on its screen makes this price gap justified.

Given that Tablet PCs would be used to replace paper, a number of decisions had to be made regarding the exact means of implementing the Paperless Classroom. One of the largest concerns is determining whether students or the academic institution must pay for Tablet PCs. In our case the experimental nature of our project precluded requiring students to pay for their own tablets, so we had to secure considerable funding for our project. There is, however, a significant argument to be made for having students pay for their own tablets.

Another prerequisite for the Paperless Classroom is having most course materials in digital form. In the case of our project, we had a bit of a head start because many materials had already been converted to the PDF or PowerPoint format because of the general advantages associated with distributing materials electronically. However, not having materials in electronic form should not prevent the move away from paper—rather, converting materials to digital format should be considered valuable in and of itself, in addition to being a requirement for the move to a paperless environment.

Related to the issue of conversion of materials is the issue of distribution of materials. In this case of this project, it was decided that the professor would convert materials (already in the PDF or PowerPoint format) into the Windows Journal format, the format most easily read and annotated by the Tablet PC. He would then post these materials to the Stellar site, a web-based distribution system already in place at MIT. While Stellar offers added benefits beyond those of a regular web site, a web site would have served the essential purpose of making digital materials available to students. On a regular day in the Paperless Classroom, it was decided the professor would upload that day's lecture slides to Stellar prior to class, and students would download the slides from Stellar using their tablets, and then use Windows Journal on their tablets to annotate the lecture slides during lecture, saving them for future use or further modification.

In order to set up and maintain the Paperless Classroom, it was determined that some special assistance besides the regular staff (Professor and TAs) was needed. Also, since this was an experimental version of the Paperless Classroom, it was necessary to assess the successes and failures of these first efforts to create a paperless environment. I was hired to fulfill all of these requirements, though even a non-experimental paperless classroom would likely have required some additional assistance beyond the regular teaching staff. Personnel and tablet costs together comprise the majority of the expense in creating a paperless classroom. A related notion is the question as to how the Paperless Classroom affects existing teaching staff. In our case, given that I was specially hired to set up and maintain the paperless environment, there was only a nominal effect on the teaching staff—the need for the professor to convert and post files to Stellar on each day of lecture.

We reviewed a wide variety of tablet hardware, with all tablets falling into one of two categories—those running Tablet XP and those not running Tablet XP. Tablet XP is the first Microsoft Operating System designed explicitly with the Tablet PC in mind and includes a number of arguably essential features, not the least of which is Windows Journal on which students' note-taking depends. Also, tablets running Tablet XP represent a new generation of hardware and are more sophisticated than their predecessors in a number of areas—most importantly in that they use an active digitizer which eliminates the *palm problem* (see section 4.2.1) that plagued nearly every tablet previously available. Among those tablets running Tablet XP, there were a number of strong offerings, however, we ultimately settled upon the Compaq TC1000 (the successor, the TC1100, is now available) as our first choice and the Acer TravelMate C100/C110 as our second choice. While these tablets were strong in many areas, we ultimately chose them because of the flexibility of their form factor—something primarily due to their both providing a graceful means of using the tablet with or without a keyboard as desired. We did not regret this decision as it gave students the greatest flexibility in using the tablets—students sometimes just used the keyboard, sometimes just used the stylus, and sometimes used both simultaneously.

In terms of software, Tablet XP provided most of what was needed—Windows

Journal was an excellent note-taking application built into Tablet XP, and any file that could be printed could be converted into the Journal format. However, it was useful to install a number of additional applications on students' tablets, with Microsoft Office arguably being the most needed and most expensive.

Backing up data is especially important in the paperless classroom because loss of data can entail loss of a semester's worth of notes and other work. While initially using a special backup service, we soon found this unnecessarily expensive and not particularly easy to use. In subsequent terms, we simply installed an FTP client on students' tablets so they could upload their notes and other files to their personal space in *afs*, where they each have a 500 MB quota, more than enough for a semester's worth of schoolwork. However, one interesting alternative is to provide each student with a USB pen drive which arguably provides the easiest and fastest means of backup without costing too much, thanks to the reasonable prices of these devices.

We determined that the best way to prepare for hardware failures was to keep a few of the least expensive and most frequently needed items on hand—namely styli and batteries. We decided not to keep on hand expensive, less frequently needed items such as hard drives and entire spare tablets. Rather, we had one tablet which was used for other purposes that could be assigned temporarily to a student in the event that their tablet had to be sent in for service.

Based upon the aforementioned implementation decisions, we distributed Tablet PCs to two undergraduate Neuroscience courses, 9.14 and 9.01, in the Spring and Fall of 2003 respectively, with a total of nine tablets in the Spring term and 24 in the Fall term. The Paperless Classroom proceeded as planned during both of these semesters with only a few minor hang-ups which primarily consisted of students having difficultly connecting to the wireless network before class, though this may have been because our wireless access point had reached the maximum number of simultaneous connections it could sustain. Additionally, we experienced one theft as well as a few broken tablet latches. However, in the end, over thirty students used the tablets instead of paper over the course of these two semesters with little trouble to speak of.

9.2 Review of Assessments

Over the course of three semesters, a variety of assessments were performed. Some of these assessments were performed for each of the three semesters—these include the LAQ, CSA, as well as analysis of the standard grade data associated with each course. A matched survey was given at the beginning and of the Spring 2003 term of 9.14 as well as at the end of the Fall 2003 term of 9.01, and exit interviews were held with all students with tablets at the end of the Spring and Fall 2003 terms. The Fall 2003 term also saw the addition of a series of quizzes and surveys which determined students' retention of material, collected some demographic information on students, and determined their motivations for requesting or not requesting tablets. Data collection software was also installed on students' tablets for the first time in the Fall 2003 term. Finally, a correlational analysis of all data collected was performed for both the Spring and Fall 2003 terms.

The LAQ showed that students were interested in learning as much as possible in 9.01/9.14 and were not concerned with performing well simply for the sake of their career plans. Tablet users worried less frequently about performing badly in 9.01/9.14 than the control group, volunteers without tablets, perhaps suggesting that tablet users gained confidence as a result of having a tablet, believing that it would confer benefits or that the tablets actually improved their performance and that they were aware of this improvement and therefore less concerned about doing badly in the course. The LAQ also showed that tablet users are more interested in mastering the material than other students. The result is an increase in their intrinsic motivation rather than an increase in their graded performance which depends more on a wish to excel in terms of grades or a wish to outperform other students.

The CSA, which determined students' learning styles, showed no significant differences found between groups and students' CSA scores did not correlate with any other measures. However, the fact that students with tablets do not differ significantly in their learning styles from other groups suggests that the tablets are suitable for students with various learning styles, as does the fact that there was significant variation in learning style within the group of students with tablets.

The significant results from the matched surveys reflected well upon the tablets. Multiple findings suggested that tablets increase organization of materials, handouts, and notes. Also, students' belief that tablets can help them organize materials, handouts, and notes, and reduce study tedium may be underlying motivational factors for their volunteering for a tablet. Finally, students who volunteer for tablets may be generally more receptive to technology used for purposes of learning.

There was little direct evidence supporting any effect of tablets on students' grades. However, figure B-38 suggests that there may be a difference between groups and that a larger sample is needed before the possibility that tablets affect grades is ruled out—tablet users during the Fall 2003 term, in fact, outperformed both other groups in every grade category albeit by an amount that was not statistically significant. Tablet users were found to care more about mastering the material than other students, whereas other students care more about getting a good grade. Since it has been shown that the latter trait is more correlative with graded performance, this may explain the lack of a significant grade change due to tablets. Since the goal of the Paperless Classroom was to remove paper while maintaining or increasing the performance of students, it was sufficient to show that tablets did not reduce performance.

Our interviews revealed that students used their tablets to take notes in almost every 9.01/9.14 lecture, and it was usually a technical issue such a problem connecting to the wireless network or human error such as the professor not posting the slides to Stellar early enough which prevented them from doing so on the remaining days. Students used tablets in other classes from a variety of departments but were much more likely to use the tablets when electronic versions of the lecture slides were already available online prior to lecture. Students were not shy about asking their professors to post lecture slides before class so they could use their tablets to take notes during lecture, and professors were apparently quite willing to put in this extra small bit of effort. This suggests that if the Paperless Classroom does continue to grow, it will largely be due to students initiating the growth.

Some students had difficulty using tablets in subjects which required highly detailed note-taking, such as Molecular Chemistry, though most students did not complain of this problem. One problem we were concerned with but that did not end up being a large problem was delay at the beginning of lecture because of the tablets—students were behind by one or two lecture slides at the beginning of lecture but did not feel that this affected them. In terms of software usage, students generally used Windows Journal, web browsing, office applications, and entertainment applications on their tablet and virtually all students have an organizational system on the tablet which groups material by course and/or by type of material (e.g. handouts, lectures, etc), placing folders with course materials in an obvious place such as *My Documents*.

Overwhelmingly, the primary change in students' note-taking behavior is their added use of color pens for a host of purposes. Most students modify their notes after the day on which they were first taken and do not have a study group, but those that do use the tablets in their study groups. All students think we should continue using tablets in 9.01/9.14 in the future, though a few students were hesitant on the basis that they weren't sure tablets were any better than paper though they didn't think they were any worse. Tablets seemed to quickly displace students' use of laptops, mainly due to their portability, and many students said they would have used the tablets for even more tasks if they'd had it for longer than a semester. Students also stated that they benefit from having the professor use a tablet as a lecture presentation device.

The retention surveys showed that tablet users were more interested in 9.01 than those who did not volunteer for a tablet, though whether this was due to their having a tablet or was instead somehow linked to the underlying reasons for their requesting a tablet is not clear. Students who volunteered for a tablet may have done so because they were more interested in new technology, more willing to try new things, less interested in improving academic performance, and less willing to accept the responsibilities associated with having a tablet. There was no difference in retention between students with tablets and those without, but this serves to show the lack of any adverse impact on students' retention of material as a result of having tablets.

Since one concern often voiced regarding having tablets or laptops in students' hands during lecture is that they will play games, check email, or surf the web instead of paying attention, the lack of any difference between groups in terms of post-lecture retention is a relevant one.

Students with tablets used flashCube significantly more than other students, possibly because they had access to the tablet, and therefore flashCube, whenever and wherever they wanted. This may suggest that students will have increased access to their notes and other schoolwork on the tablet, improving their performance in the course. swClient showed that tablet usage correlated with a student's interest in having a tablet because of a desire to improve academic performance, perhaps because a student who wishes to improve his performance may study more, and may do so using the tablet. swClient also showed that there is no particular correspondence between total tablet usage and usage for 9.01 specifically. Rather, those students who used the tablets the most did not use the tablet for 9.01 any more than those who used the tablet much less, indicating that students who used the tablet more frequently were using it more frequently because they used it for a wider variety of tasks or classes, not because they were using it more for 9.01.

Correlational analysis primarily revealed connections between items from the same assessment type which served to validate the data for the measure in question. Correlations between measures from different categories provided more interesting findings including the fact that students are aware of their performance level in the class and the fact that if a given student is positive regarding one aspect of the tablets, then they are positive regarding all aspects of the tablet. A link was also established between students' interest in, enjoyment of, interest in learning, and retention of, course material. There was also a correlation between motivation to outperform peers and organization of materials, a correlation between extremely short term (same-day) retention and somewhat short term (on the order of one week) retention, a negative correlation between fear of performing poorly and enjoyment in class, and a correlation between self-reported stress level and time spent studying outside of class. With the exception of the aforementioned swClient correlation, no significant correlational relationship was found between tablet usage and other measures. There were no significant correlations between any tablet related measure and any grade related measure.

9.3 Synthesis of Findings

I will now bring all of these findings together in an attempt to form an overall picture of the Paperless Classroom and our findings regarding it. Conclusions regarding the Paperless Classroom fall into four categories—those which characterize 9.01/9.14 students in general, those which characterize students who volunteer for tablets, those which describe what appear to be the effects tablets have on students they are provided to, and those which describe observational findings regarding the actual Paperless Classroom experience.

9.3.1 Students in General

The students in 9.01/9.14 were interested in learning as much as possible in the course and were not concerned with performing well simply for the sake of their career plans. It would seem, however, that some students are motivated by outperforming their peers and these students tend to be more organized, perhaps as a result. Furthermore, they were aware of their performance level in the class at a given time and their enjoyment of the course is related to that perceived performance. Also, their stress level corresponds to the amount of time they spend working on 9.01/9.14 outside of class. Students' general interest in 9.01/9.14 is tied to their interest in learning the material as well as their enjoyment and very short-term retention of that material, which is in turn related to their semi-short term retention, as shown in quiz scores. It may also be that 9.01/9.14 students are slightly wholistic in their learning style, thinking of problems systemically rather than decomposing them into subcomponents.

9.3.2 Students Who Volunteer

Students' belief that tablets can help them organize materials, handouts, and notes, and reduce study tedium may be underlying motivational factors for their volunteering for a tablet. Students who volunteer for tablets may, in fact, be generally more receptive to technology used for purposes of learning in that they are more interested in new technology, and more willing to try new things. It would also seem that students who volunteer for tablets are less interested in improving academic performance, and less willing to accept the responsibilities associated with having a tablet than those who do not volunteer.[1] It was also found that if a given student is positive regarding one aspect of tablets, then he is positive regarding all aspects of tablets, and the same holds for students who are negative about tablets.

9.3.3 The Effect of Tablets on Students

In most cases, it was possible to compare tablet users to an ideal control group which consisted of students who had volunteered for a tablet but had not received one. Thus differences between these two groups does imply a causative effect due to the tablets. Tablet users worried less frequently about performing badly in 9.01/9.14 than the control group which may suggest that tablet users gained confidence as a result of having a tablet, believing that it would confer benefits. It may also be that the tablets actually improved their performance and they were aware of this improvement and therefore more confident. Tablet users were more interested in course material and had more organized materials, handouts, and notes than the control group. While the tablets did not have a significant effect on students' grades, a larger sample is needed before the possibility is ruled out—tablet users during the Fall 2003 term, in fact, outperformed both the control group and students who did not volunteer for a tablet in every grade category albeit by an amount that was not statistically significant. In fact, there were no significant correlations between any tablet related

[1]Though the latter finding may merely be due to students with tablets already having had these responsibilities when they completed the survey which asked them about their original motivations for requesting a tablet.

measure and any grade related measure. The lack of grade change may be due to tablet users' greater interest in mastering material, and their slightly lower interest in simply achieving a high grade, relative to students without tablets. It has been shown that the pursuit of mastery does not result in grades as high as a direct pursuit of high grades. But since the goal of the Paperless Classroom was to remove paper while maintaining or increasing the performance of students, it was sufficient to show that tablets did not reduce performance.

Overwhelmingly, the primary change in students' note-taking behavior as a result of having a tablet is their added use of color pens. Most students modify their notes after the day on which they were first taken, though it is not known how this compares to those using paper. Those students that have a study group use the tablets while working with them. Tablets seemed to quickly displace students' use of laptops, mainly due to their portability, and many students said they would have used the tablets for even more tasks if they'd had it for longer than a semester. A connection was found between a student's rate of tablet usage and their interest in having a tablet because of a desire to improve academic performance, perhaps suggesting that students who have a desire to improve performance do so by using the tablet more. Students with tablets also used flashCube significantly more than other students, suggesting they have a general advantage over other students in terms of their access to the software, something which should, in turn, suggest they have greater access to digital materials in general.

9.3.4 Observational Findings

Students used tablets in a variety of courses besides 9.01/9.14 but were much more likely to use the tablets when electronic versions of the lecture slides were already available online prior to lecture. Some students asked their Professors to post lecture slides before class so they could use their tablets to take notes during lecture, and Professors willingly did so. This spontaneous move on the part of our tablet users suggests that if the Paperless Classroom does continue to grow, it will largely be due to students backing it.

It would, in fact, seem that some students used their tablets extensively for classes other than 9.01/9.14—those students who used the tablets the most did not use the tablet for 9.01 any more than those whose overall usage was lower, indicating that students who used the tablet more frequently were using it more frequently because they used it for a wider variety of tasks or classes, not because they were using it more for 9.01.

However, some students had difficulty using tablets in subjects which required highly detailed note-taking, but these students were in the minority. One potential problem turned out not to be much of an issue—namely, the delay at the beginning of lecture because of the tablets was minimal, according to students. The two most frequently cited things preventing students from using their tablets on a given day were problems connecting to the wireless network and the professor's delay in posting lecture slides to Stellar. The latter, at least, is correctable, and the former issue may have been due, in part, to the over-utilization of our wireless access point which is an easily solved problem (e.g. by using USB memory sticks or Bluetooth-based networks).

Perhaps what matters most is that students think we should continue using tablets in 9.01/9.14 in the future.

9.4 Final Conclusion

The student population being studied consisted of a group that was, overall, quite enthusiastic about learning the material, and it would seem that the greater the enthusiasm, the greater the retention of material. To whatever extent this group is representative of students elsewhere, our results should be applicable to students elsewhere. While the extent to which this group does, in fact, resemble student populations elsewhere is not known, but the sample did consist of a wide variety of students from various departments, albeit with a slight tendency to contain students from the department of Brain and Cognitive Sciences. In any case, as shown by the CSA, these students' learning styles are intermediate in terms of their verbaliser-imager component, but are slightly more wholistic than analytic.

Students who volunteer for tablets seem to do so because they believe tablets will help them organize materials, handouts, and notes, and reduce study tedium. Our findings showed that these volunteers' beliefs regarding organization, if not those regarding tedium, are founded in fact. Our findings also indicate that students who volunteer for tablets may be more motivated to do so because of their interest in trying new things than they are because of a wish to improve academic performance. The benefits for those who do receive a tablet are, in some cases, clear—tablet users are more confident in their performance in the course, presumably either because the tablet actually helped them or at least because they thought it did. Tablet users were also showed higher motivation and interest in course material. Interest in the course has been found to be a predictor of retention which presumably results in increased performance. While the data did not seem to suggest such an increase in performance, they did seem to suggest the possibility of the detection of a grade increase due to tablets with the use of a larger sample.

Not only did students with tablets claim to benefit from being able to read all their handouts in color, but they without exception made greater use of color in the act of note-taking—most students had not, in fact, used color at all in their note-taking prior to having a tablet but all of them did so after having the tablet. Students found it easy to locate their old notes and most students modified their notes after the day on which they were first taken. Tablets seemed to quickly displace students' use of laptops, mainly due to their portability, and many students said they would have used the tablets for even more tasks if they'd had it for longer than a semester. There were also indications that students who have a desire to improve performance do so by increasing their use the tablet, presumably to review old notes or access material on Stellar. Tablet users also have greater access to software than other students, something which may suggest they have greater access to digital materials in general.

Students were much more likely to use the tablets when electronic versions of the lecture slides were already available online prior to lecture, thus expansion of the Paperless Classroom is clearly contingent upon the continued digitization of course materials and subsequent upload to a web-based content delivery system such as Stellar. While these duties largely depend on course instructors, it is clear that the expansion of the Paperless Classroom depends on students' efforts, encouragement, and feedback as well.

Other than occasional problems with the wireless network and the rare failure on the part of the professor to post lecture slides early enough, the tablet users were able to take notes using the tablet instead of paper during virtually every lecture. This, coupled with the host of aforementioned benefits afforded by the tablets, may account for the vast majority of these tablet users believing that we should continue using tablets in the future and our study of the Paperless Classroom has provided adequate evidence to justify that belief.

9.5 Future Work

Recommended follow-up Paperless Classroom efforts fall into two categories—those which expand upon and improve the actual Paperless Classroom implementation, and those which improve and expand upon the study of the Paperless Classroom.

9.5.1 Implementation Enhancements

One question that still needs to be resolved, perhaps on a case by case basis, is who would be required to pay for tablets in a greatly expanded implementation of the Paperless Classroom—the students or the academic institution. In the experimental stages, there is no way students can be required to have their own tablets so the institution must therefore pay. However, the institution may be overburdened by maintaining a large scale implementation, suggesting that distribution of the cost and upkeep of tablets to students is necessary. The question is simply whether students should be given this additional burden. Given the benefits tablets have been shown to afford students, it may well be worth it to them. This issue is the single largest one that needs to be solved and may even merit formal study.

Further expansion of the Paperless Classroom at MIT first and foremost depends on solving the above issue, but also carries additional requirements. While other efforts such as *Stellar* and *Open Course Ware* at MIT have accelerated the digitization of materials, some courses still use paper exclusively, and to maximize the usefulness of tablets, these courses will need to make the switch to digital materials as well. Once this is done, it is still helpful for the instructor or TA to convert materials to the Journal format since it saves an entire class of students from having to do so themselves. But in order to be useable by students without tablets, PDF versions must also be retained. This brings up the next potential area of improvement.

The software industry has some great opportunities to improve existing software for Tablet PCs. For example, if Adobe Acrobat and Windows Journal could somehow be combined, the result would be an amazing piece of software—Acrobat offers the incredibly standard, cross-platform readable PDF format and an extensive set of tools for creating PDFs but has extremely poor annotation tools, only providing an eraser tool in its most recent release, Acrobat 6. Windows Journal, on the other hand, provides an excellent set of annotation tools but is an extremely nonstandard format, by default only being readable on other Tablet PCs, though an optional download is available for users of Windows XP. This leaves all remaining versions of Windows, not to mention MacOS X and Unix systems with no means of reading Journal format files.

A tablet user must own the full version of Adobe Acrobat and use it to convert the Journal file to a PDF before it can be expected to be read by anyone else, and this is absolutely far too much to expect of the user. Solving this problem would either require Acrobat to add the wonderful functionality of Windows Journal or for Windows Journal to add the capabilities of Acrobat and simultaneously become a widespread format. Of the two, the former sounds more likely. A third option would be some sort of collaboration between Microsoft and Adobe, but I would not venture to guess the likelihood of that happening. In any case, I voiced my concerns to the Project Manager in charge of Acrobat, but my comments, assuming they were considered important, probably came too late to be incorporated into Acrobat 6. Perhaps Acrobat 7 will be the answer to this dilemma.

The Paperless Classroom itself went quite smoothly, but there are still a few wrinkles to be ironed out. Further research into the causes of and cures for problems with the wireless network would be of great use. A full study of different wireless cards, access points, and operating systems and their degree of interoperability would likely shed some light on the subject, though the wireless functions in Tablet XP (and other Microsoft operating systems) clearly leaves something to be desired—given that the user is able to solve some problems simply by disabling and re-enabling the wireless adapter, it seems reasonable to conclude that those particular problems are software issues, namely Windows issues. However, it may also be that we were over utilizing the wireless access point in our lecture hall, something which must be formally determined and then properly solved if necessary.

There are few remaining issues, all of them mostly solved. For example, we have not quite settled on the ideal backup method for students, but the means previously used worked relatively well. the professor must be ever so slightly more diligent in posting lecture slides prior to class or must delegate this task to a TA, assuming that it is feasible to do so. We also have yet to work out a formal tablet loan contract with students which protects us without making them subject to unfair penalties. However, these issues are relatively minor and we will surely find ways of handling each of them.

9.5.2 Follow-up Research

While a great deal of data was collected and analyzed during this study, and while there were some significant findings, they were not adequate in proving that the move to tablets and away from paper is an essential one though they did show a number of advantages of tablets over paper. The next step in studying the paperless classroom requires an increase in scale—it will either be necessary to use larger numbers of students within a given course, or to use a larger number of courses coupled with some statistically valid means of pooling data from different courses, perhaps by normalization of the data prior to statistical analysis. An increase of sample size to, say, $n = 100$ for the experimental and control groups would undoubtedly be possible and adequate in terms of revealing any effects tablets have on grades and other measures. Recall that there were a total of 33 tablet users over both semesters (not counting the Fall 2002 in which students were given antiquated tablets for about a week)—nine tablet users in the Spring of 2003 and 24 in the Fall of 2003.

In addition to increasing the sample size, follow studies may want to consider measuring factors which were not measured in our study, or revisiting those which were not adequately studied. The matched surveys, for example, should undoubtedly be used again with a larger sample because the beginning-of-term survey was only offered once, during the Spring 2003 term, in which the sample was extremely small, with 25 students in all, only nine of whom were tablet users. A less than optimal response rate further reduced the chances that comparison of the beginning- and end-of-term survey results would result in any significant findings.

While we did use software to determine students' tablet usage, the introduction of this software came late in the term and one of the software packages, *Codename Alvin* exhibited undesirable behavior not discovered during testing that required us to remove it. This notion of using software to track students' tablet usage therefore represents a virtually unexplored domain and a large sample coupled with reliable and powerful tracking software from the first day of tablet distribution would undoubtedly result in additional findings. The only concern with such software is students' privacy, but using proper data filtration methods, students' privacy can be protected along with the data.[2]

While some discoveries were made regarding students' motivations for requesting a tablet and the relationship between those motivations and other factors, a more thorough study which focused on this topic might be expected to produce better results. Furthermore, knowing what types of students thrive with tablets and which ones have difficulties would be highly useful and no discoveries were made along these

[2]For example, my plan with Codename Alvin, had it functioned properly, was to write a small program which would extract interesting features from the data it provided and discard the rest. Thus we might know when or how often students visited the Stellar site or other specific web pages of interest, but we would not know what other, potentially private, sites they visited. We might know when and how often they viewed their notes in Windows Journal, or used Eudora, or WebMail, but would not know the contents of their email, for example.

lines. In fact, multifactor analysis was not performed on the data, and this would be a prerequisite for making such determinations. It is possible, for example, that students' learning styles, as measured by the CSA or some other measure, interact with tablet usage in a way that affects performance. Future studies focusing on making such discoveries are clearly in order.

Finally, formal study of the costs and savings of Paperless Classroom implementations of varying size and type might reveal whether the benefits afforded by tablets ultimately outweigh the costs. Such studies could also determine whether the paperless classroom does represent an increase in total costs, or if the savings due to reduction in paper infrastructure exceed the cost of using tablets, resulting in a net savings.

Appendix A

Tables

Table A.1: A List of Questions in the Learning Attitudes Questionnaire (LAQ)

	Please answer these questions on a scale from 1 to 7 where: **1** means *not at all true of me* and **7** means *very true of me*
1	In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.
2	My goal in this class is to get a better grade than most of the students.
3	I worry about the possibility of getting a bad grade in this class.
4	Knowing the material for this class will help me get into medical school.
5	It is important for me to understand the content of this course as thoroughly as possible.
6	It is important to me to do well compared to others in this class.
7	In a class like this, I prefer course material that really challenges me so I can learn new things.
8	My goal for this class is to avoid performing poorly.
9	I want to do well in this class to show my ability to my family, friends, advisors, or others.
10	I want to learn the material in this class so I will be prepared take the more advanced Neuroscience classes in the future.
11	I wish to completely master the material presented in this class.
12	I want to learn as much as possible from this class.
13	I'm afraid that if I ask my TA or instructor a "dumb" question, they might think I'm not very smart.
14	I am striving to demonstrate my ability relative to others in this class.
15	It is important to me to do better than the other students.
16	This class is important for me to understand because it is relevant to my career plans.
17	I want to learn the material in this class because it will complement some of the non-Neuroscience courses I wish to or have already taken.
18	I just want to avoid doing poorly in this class.
19	I often think to myself, "What if I do badly in this class?"
20	Knowing the material for this class will help me get into graduate school.
21	I want to learn the material in this class because it will make me well-rounded academically.
22	I am motivated by the thought of outperforming my peers.
23	I hope to have gained a broader and deeper knowledge of Neuroscience when I am done with this class.
24	If I don't do well in this class, I will have to change my career plans.
25	My fear of performing poorly in this class is often what motivates me.

Table A.2: A List of Questions in the Matched Survey

	Rate the following questions on a 1 to 10 scale: **1** is *absolutely no, not in the slightest* and **10** is *wholeheartedly and undoubtedly yes*
1	Do you enjoy your in-class experience in 9.14?
2	Do you enjoy time spent on 9.14 outside of lecture?
3	Is studying for 9.14 tedious?
4	Regardless of your answer to (3), would having a tablet decrease the tedium in your studies in 9.14?
5	Regardless of your answer to (3), would having learning software customized for 9.14 decrease the tedium in your 9.14 studying?
6	Would having the tablet improve your understanding of 9.14 material due to its ability to display all handouts in color (as opposed to black-and-white handouts)?
7	How many hours per week of your time do you think a tablet would save you? That is, to achieve a given amount of learning or progress, how much less time per week would be required if you had a tablet (negative answers are accepted)?
8	Would a tablet help you to better organize materials and handouts for 9.14?
9	Would a tablet help you to organize your own notes for 9.14?
10	Would a tablet help you organize your time better (in any way, not just for 9.14)?
11	Are you currently successful at organizing materials and handouts for 9.14?
12	Are you currently successful at organizing your own notes for 9.14?
13	Are you currently successful at organizing your time (in general)?
14	To whatever extent you feel a tablet might be useful in 9.14, how much of that usefulness depends on the existence of a stellar site for 9.14 (1 = none 10 = all)?
15	If you had to guess, what letter grade would you expect to get in 9.14?
16	How many hours per week outside of class do you spend on 9.14?

Table A.3: A List of Questions Asked During Exit Interviews with Tablet Users

1	What percentage of days do you use the tablet in 9.01/9.14?
2	Did you use the tablet in your other classes, and why or why not?
3	Please give any positive or negative comments about tablets and their use in the Paperless Classroom.
4	How often are you not yet ready to take notes at the beginning of class because you're using a tablet and not paper?
5	What programs have you used, in order of frequency (every day, every week, and just occasionally)?
6	How would you characterize the way you store files on the tablet?
7	What do you have to say about your note taking habits and how they might have changed since getting the tablet?
8	Do you ever modify notes for a given class after the day on which you originally took the notes?
9	Do you participate in a study group? Do any of them have a tablet? How are tablet(s) used during the group study sessions? How do those without tablets react to the tablet?
10	What would you recommend for future classes—should we keep having the tablets?
11	What other study equipment (e.g. laptop, desktop, Athena) do you use and how?
12	Did you like it when Prof Schneider used the tablet to draw in class?

Table A.4: A List of Software Students Used on a Daily or Near-Daily Basis (The number of students citing usage is given on the left.)

25	Windows Journal
18	Internet Explorer
12	AOL Instant Messenger
9	Opera
7	Microsoft Word
2	Netscape
2	FileZilla (FTP)
2	Winamp
2	Adobe Acrobat
1	Secure CRT (telnet)
1	Windows Media Player
1	iTunes
1	Windows games

Table A.5: A List of Software Students Used on a Weekly Basis (The number of students citing usage is given on the left.)

8	Microsoft Word
3	FileZilla (FTP)
2	Opera
2	Adobe Acrobat
2	Windows Media Player
2	Kazaa / Kazaa Lite
2	AOL Instant Messenger
1	Windows Calc
1	flashCube (flashcard software)
1	Sticky notes (Tablet PC post-it note application)
1	Adobe Photoshop
1	RealPlayer

Table A.6: A List of Software Students Used on an Occasional Basis (The number of students citing usage is given on the left.)

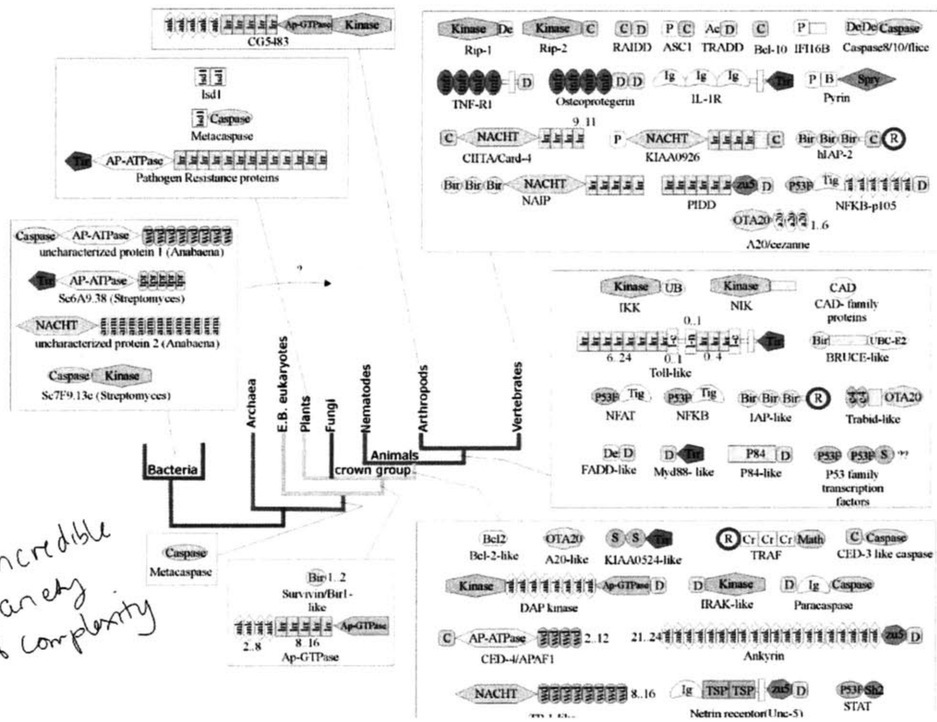
3	Microsoft Word
3	Microsoft Excel
2	flashCube (flashcard software)
2	Windows Paint
2	FileZilla (FTP)
1	Windows Freecell (solitaire)
1	Spider Solitaire
1	Windows InkBall (stylus-based game)
1	RealPlayer
1	SecureFX (FTP)
1	Adobe Acrobat
1	Internet Explorer
1	Windows Media Player
1	Sticky Notes (Tablet PC post-it note application)

Table A.7: A List of Mappings from Node Names to the Measure they Represent in Correlation Graphs

Node Color	Node Name	Assessment Measure Corresponding to Node
Dark Blue	prsX	Beginning-of-term Survey (a.k.a. Pre-Survey) Question Number X
Light Blue	pstX	End-of-term Survey (a.k.a. Post-Survey) Question Number X
Yellow	laqX	Learning Attitudes Questionnaire (LAQ) Question Number X
Gold	Mastery	Learning Attitudes Questionnaire (LAQ) Mastery goal
Gold	pApproach	Learning Attitudes Questionnaire (LAQ) performance-approach goal
Gold	pAvoid	Learning Attitudes Questionnaire (LAQ) performance-avoidance goal
Gold	Career	Learning Attitudes Questionnaire (LAQ) career-related goal
Gold	IntrinsicMotivation	Learning Attitudes Questionnaire (LAQ) derived Intrinsic Motivation level
Gold	GradePrediction	Learning Attitudes Questionnaire (LAQ) derived Grade Performance level
Red	Mid or Midterm	Midterm Score
Red	Fex or Final_Exam	Final Exam Score
Red	Attendance	Attendance as Determined by Number of Missed Quizzes
Red	QzAv or quiz_mean_with_zeros	Quiz Average Which Treats Missed Quizzes as Zeros
Red	quiz_mean_without_zeros	Quiz Average Which Ignores Missed Quizzes
Red	HwAv	Homework Average
Red	Paper_Mean_with_Zeros	Average Paper Grade Counting Missed Papers as Zeros
Red	Paper_Mean_without_Zeros	Average Paper Grade Which Ignores Missed Papers
Red	Fin or Final_Grade	Final Composite Grade in the Course
Red	GPA_cumulative	Retention Survey Question—Self-reported Cumulative MIT GPA
Pink	Interest_in_Lectures	Retention Survey Question—Degree of Interest in 9.01 Lectures
Pink	Interest_in_9.01	Retention Survey Question—Degree of General Interest in 9.01
Pink	Computer_Familiarity	Retention Survey Question—Degree of Familiarity with Computers
Pink	Retention_all_classes	Retention Survey Question—Degree of Retention of Material in All MIT Courses
Pink	try_new_things_disinterest	Didn't volunteer because of Disinterest in Trying New Things
Pink	new_technology_interest	Volunteered because of Interest in New Technology
Pink	new_technology_disinterest	Didn't volunteer because of Disinterest in New Technology
Pink	new_learning_strategies_interest	Volunteered because of Interest in New Learning Strategies
Pink	new_learning_strategies_disinterest	Didn't volunteer because of Disinterest in New Learning Strategies
Pink	improving_academic_performance_interest	Volunteered because of Interest in Improving Academic Performance
Pink	improving_academic_performance_disinterest	Didn't volunteer because of Disinterest in Improving Academic Performance
Pink	associated_responsibilites_interest	Volunteered because of Willingness to Accept Associated Responsibilities
Pink	associated_responsibilites_disinterest	Didn't volunteer because of Unwillingness to Accept Associated Responsibilities
Pink	using_paper_interest	Volunteered because of a Dispreference for Using Paper
Pink	using_paper_disinterest	Didn't volunteer because of a Preference for Using Paper
Brown	Grade_X	Retention Survey—Daily Quiz Score, Day X
Brown	Grade_mean	Retention Survey—Average Daily Quiz Score
Brown	Retention_X	Retention Survey—Self-reported Retention Level, Day X
Brown	Retention_mean	Retention Survey—Average Self-reported Retention Level
Brown	Stress_Level_X	Retention Survey—Self-reported Stress Level, Day X
Brown	Stress_Level_mean	Retention Survey—Average Self-reported Stress Level

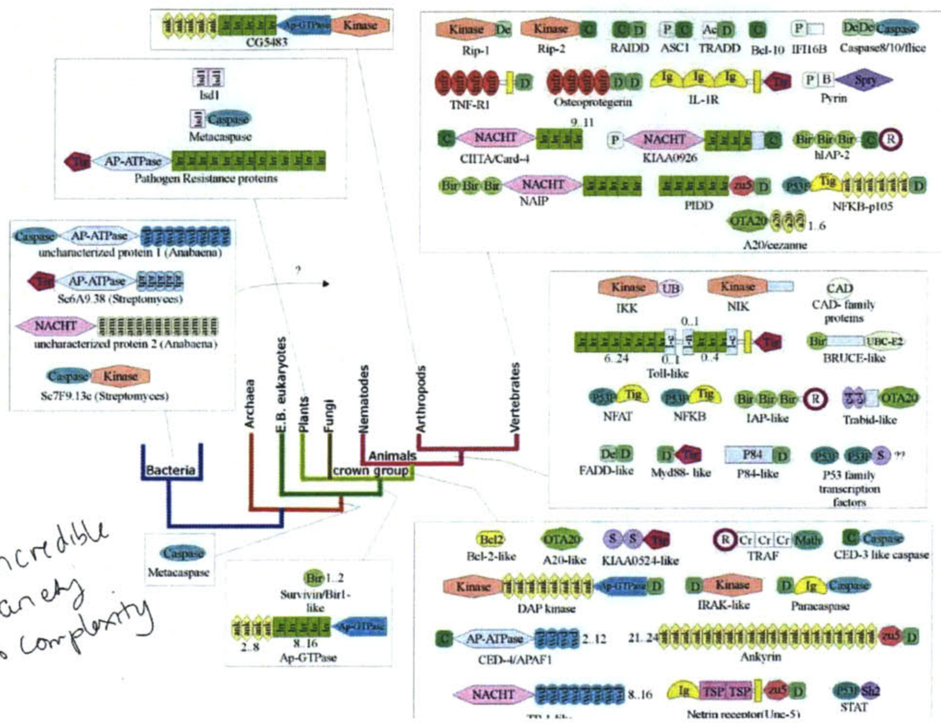
Appendix B

Figures



incredible variety & complexity

Figure B-1: The black-and-white version of a page in which color would have provided additional information and clarity [2]



incredible variety & complexity

Figure B-2: An example of a page in which color provides additional information and clarity [2]

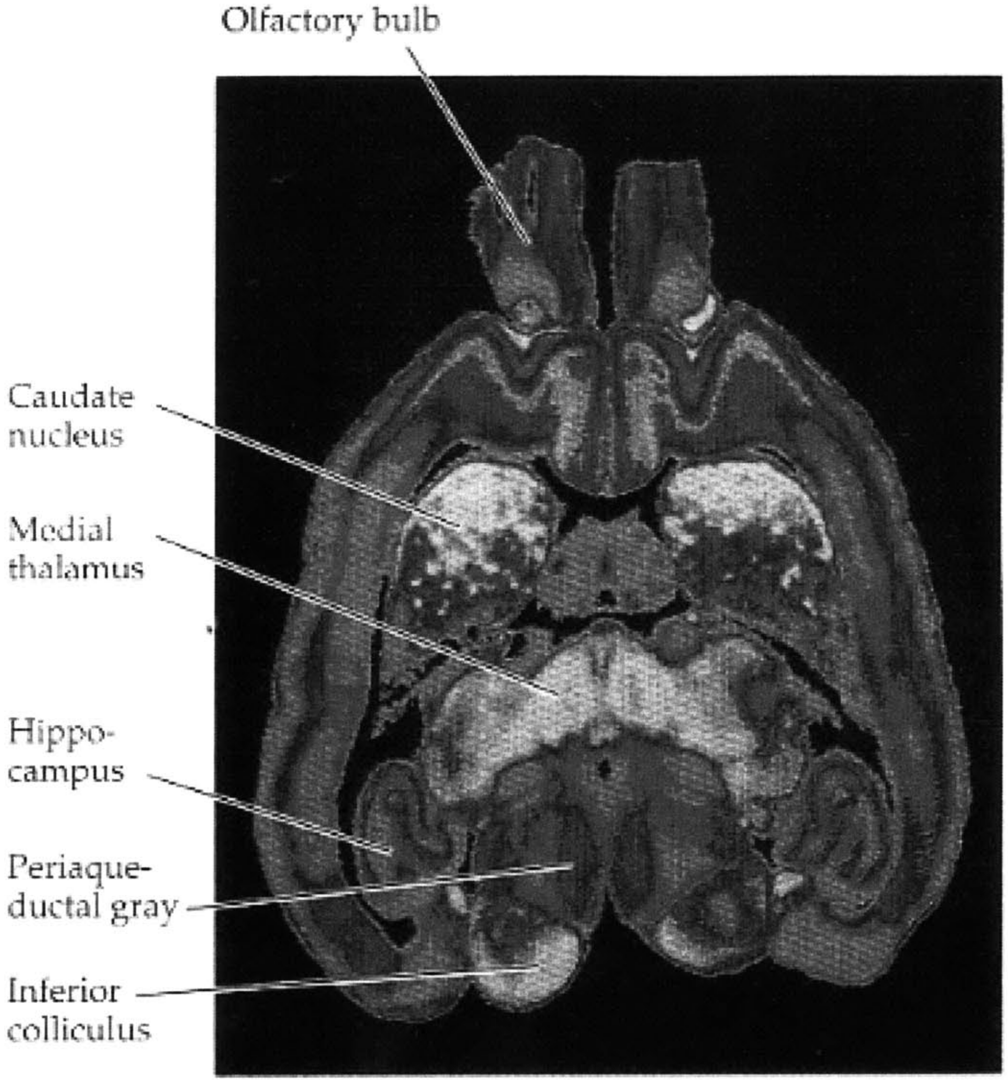


Figure B-3: Another example of the limitations of black-and-white diagrams [36]

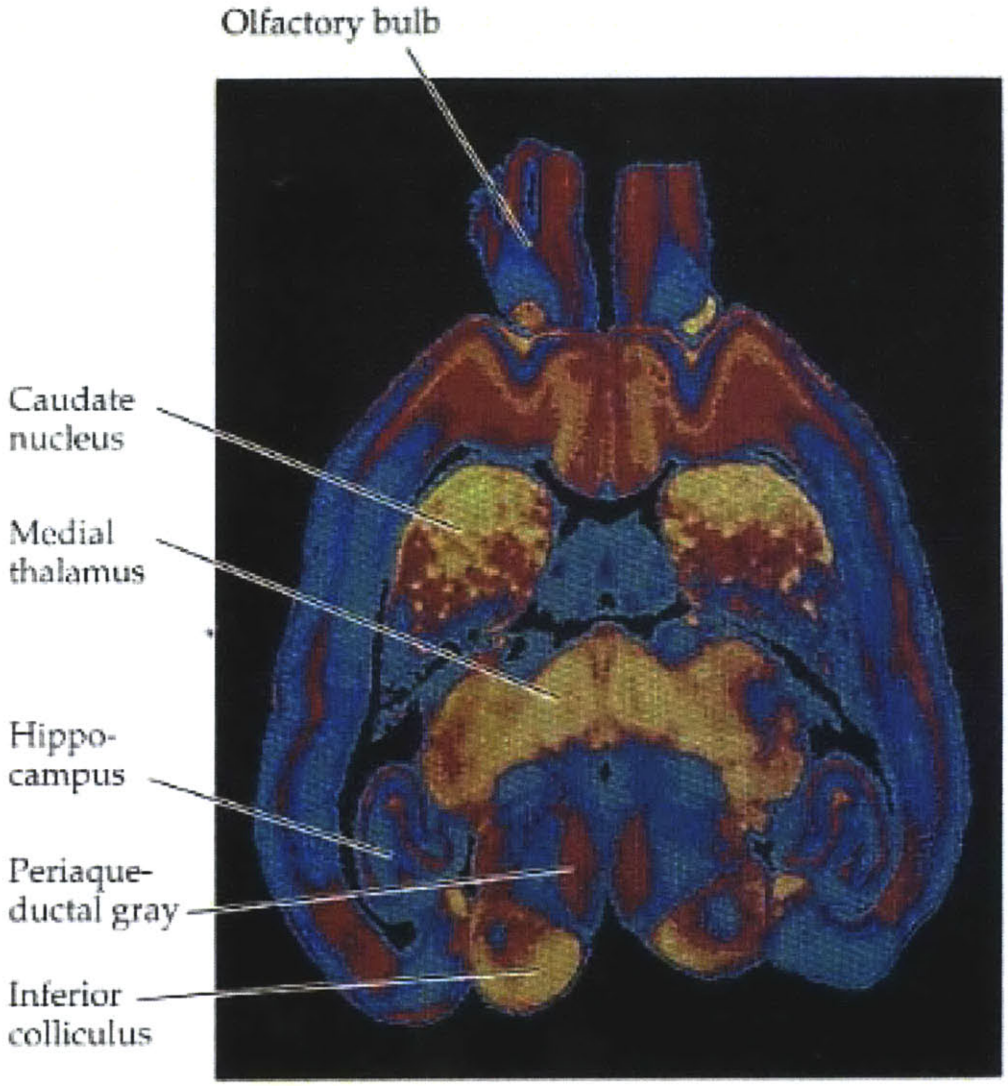


Figure B-4: Another example of the benefits of color in diagrams [36]

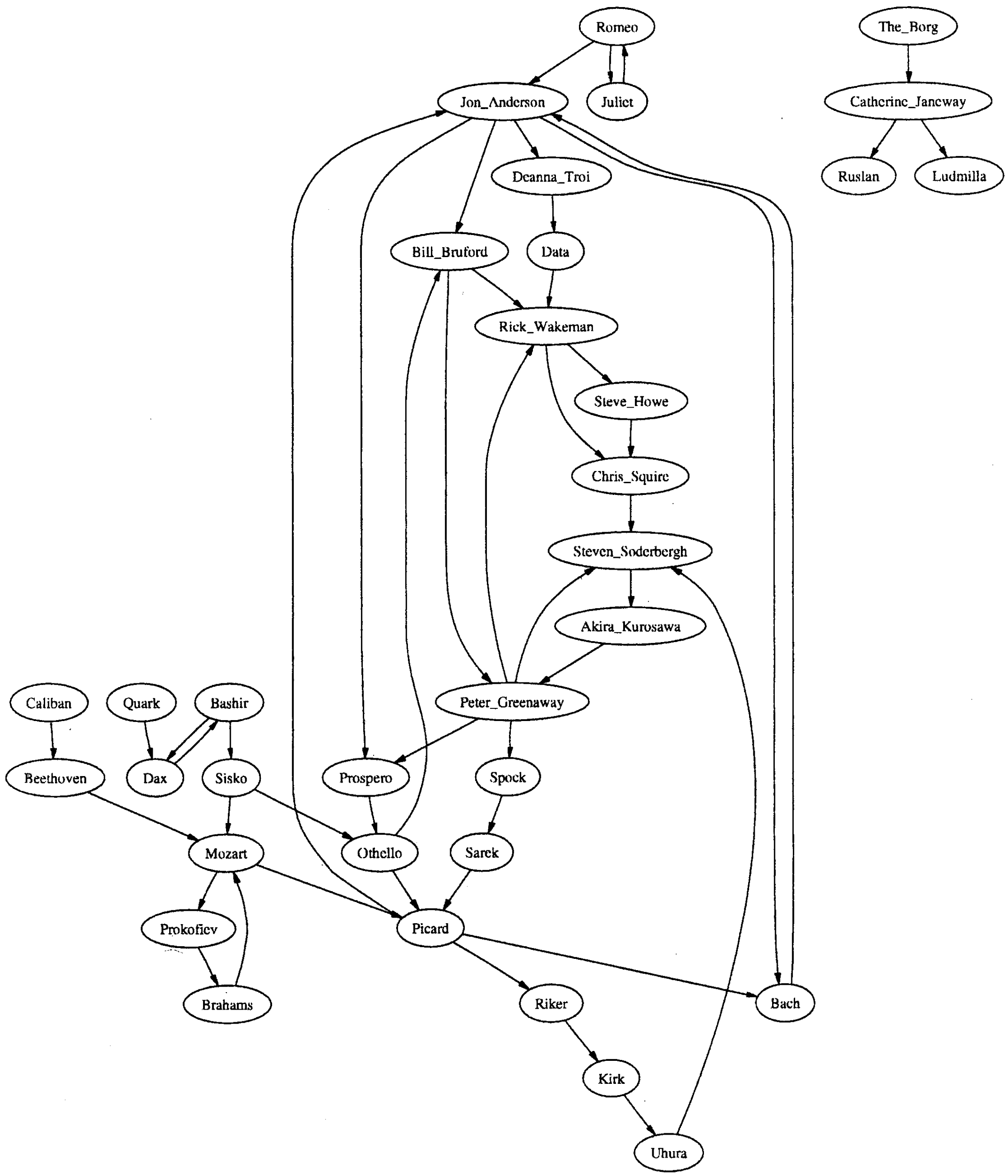


Figure B-5: The Diagrammatical Representation of Relationships between People

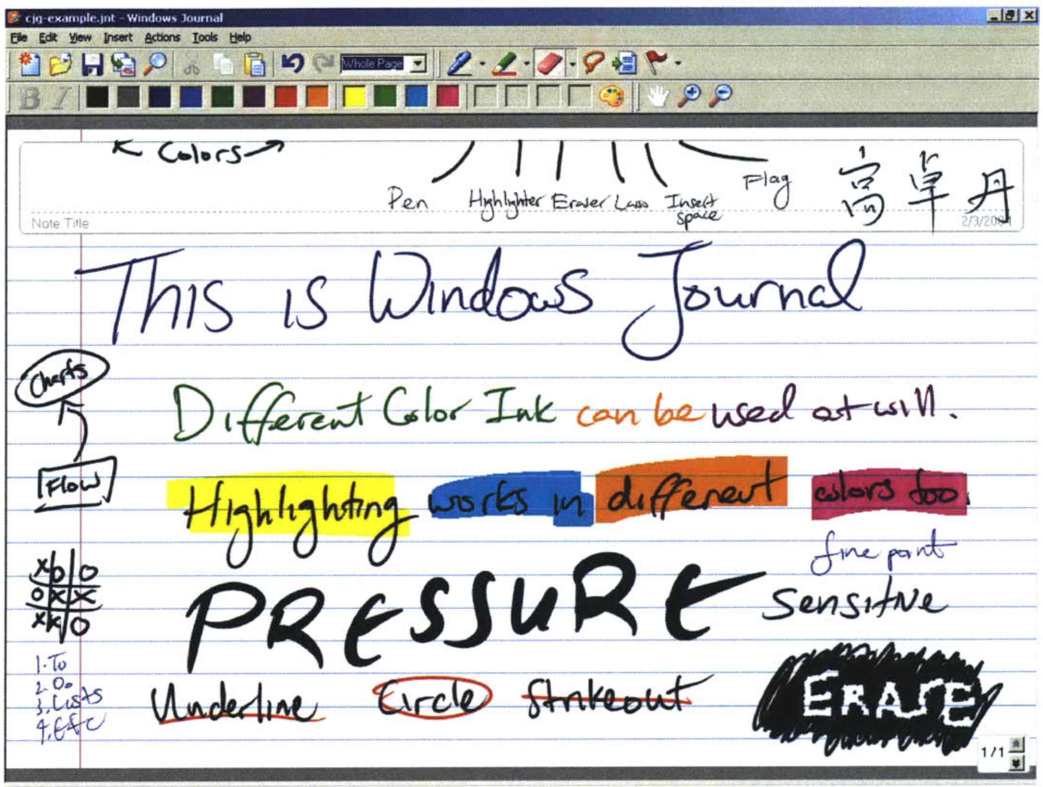


Figure B-6: A screenshot of the Windows Journal notetaking application

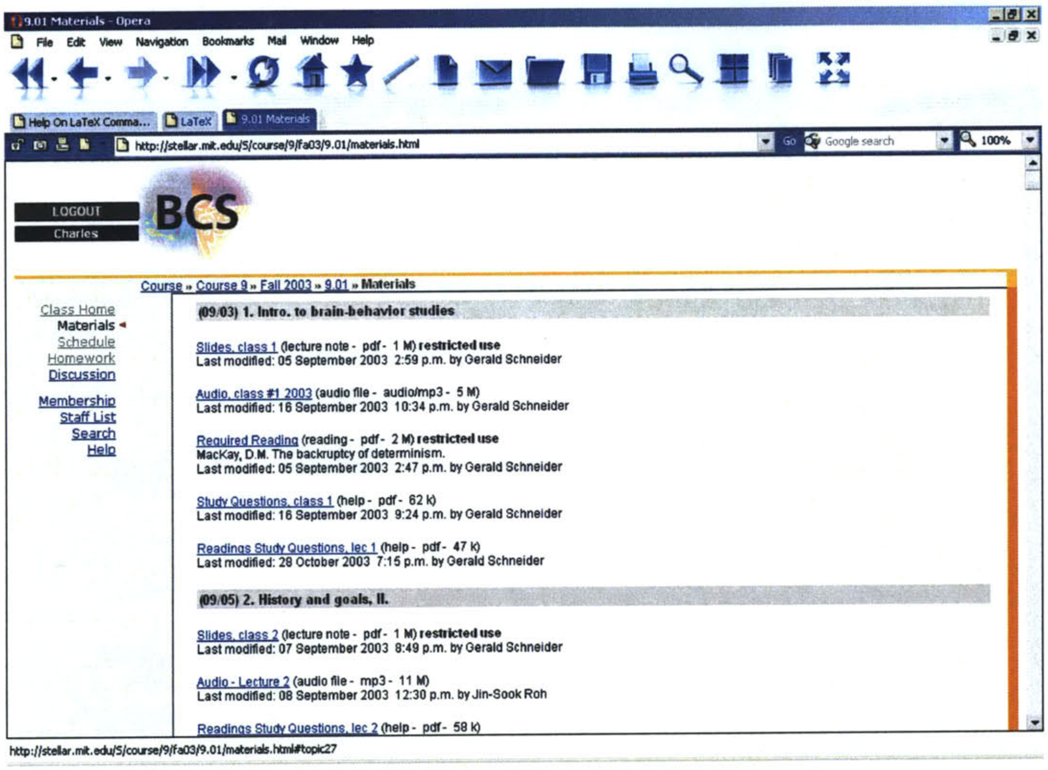


Figure B-7: A screenshot of the Stellar Course Management System used at MIT

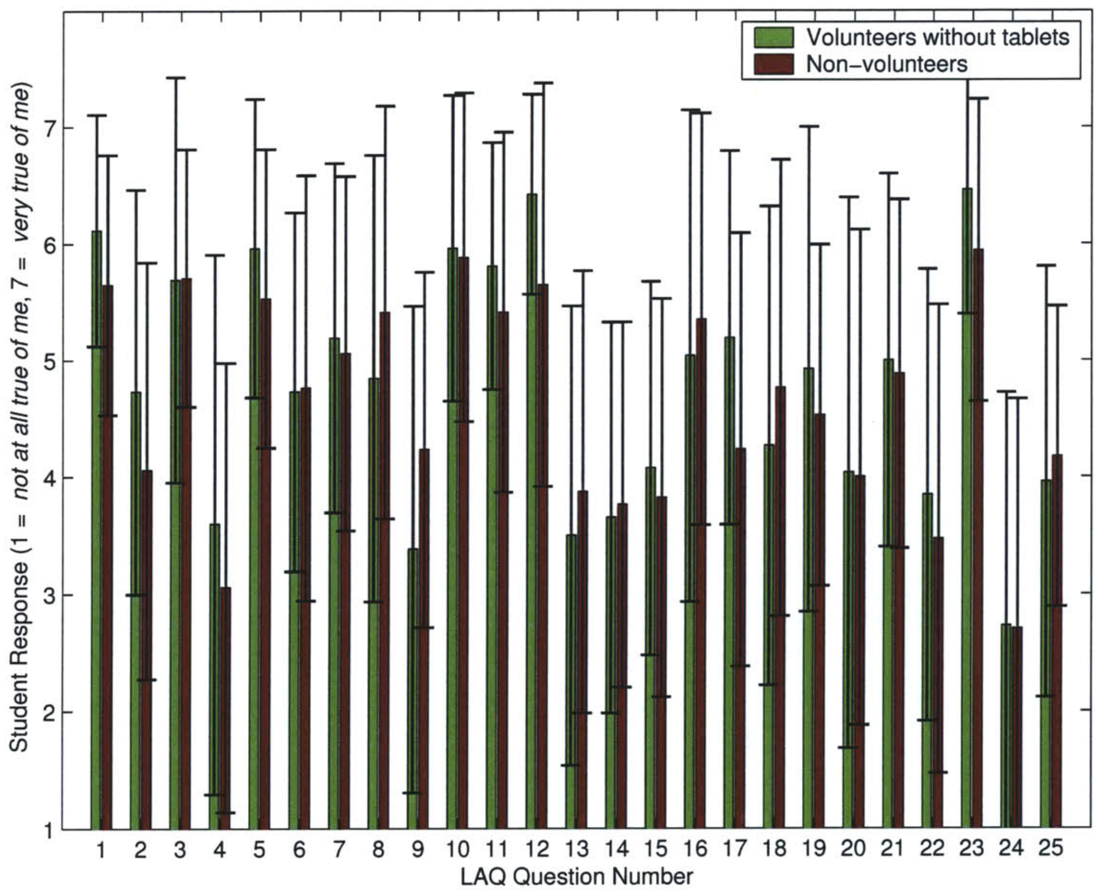


Figure B-8: Learning Attitudes Questionnaire (LAQ) Results—9.01, Fall 2002

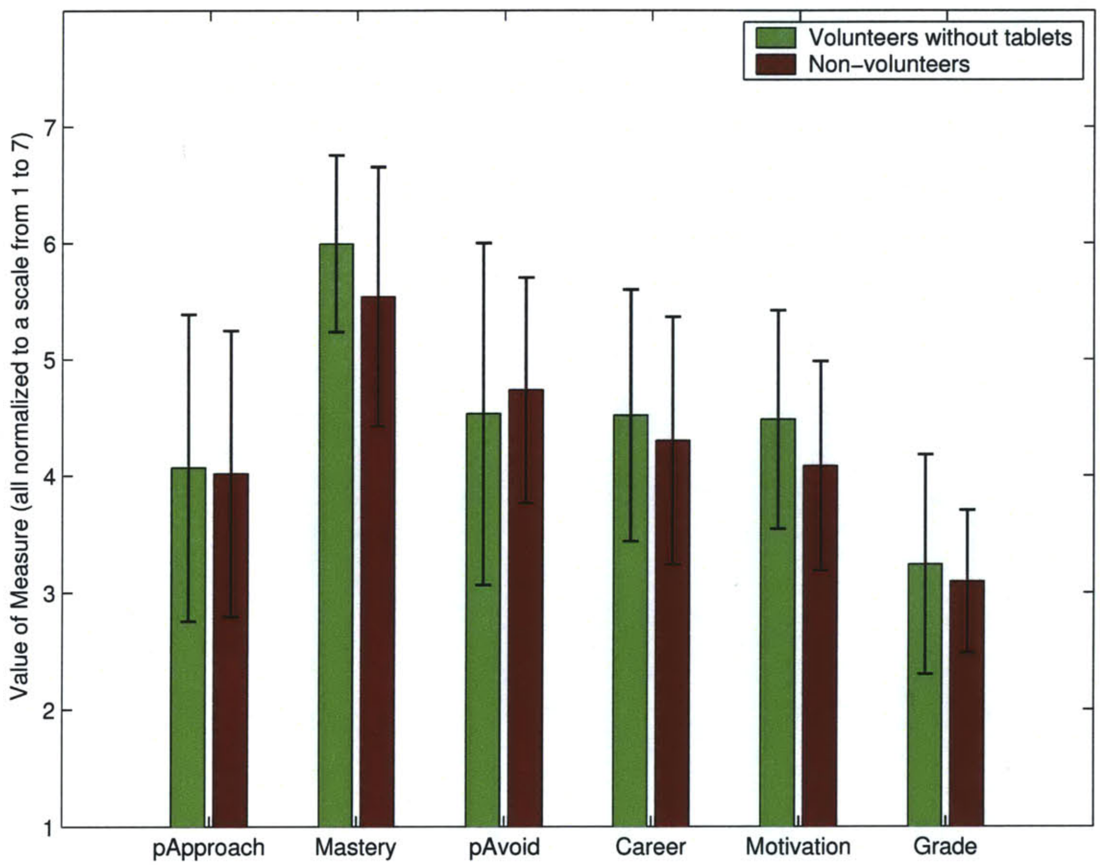


Figure B-9: Learning Attitudes Questionnaire (LAQ) Meta Results—9.01, Fall 2002

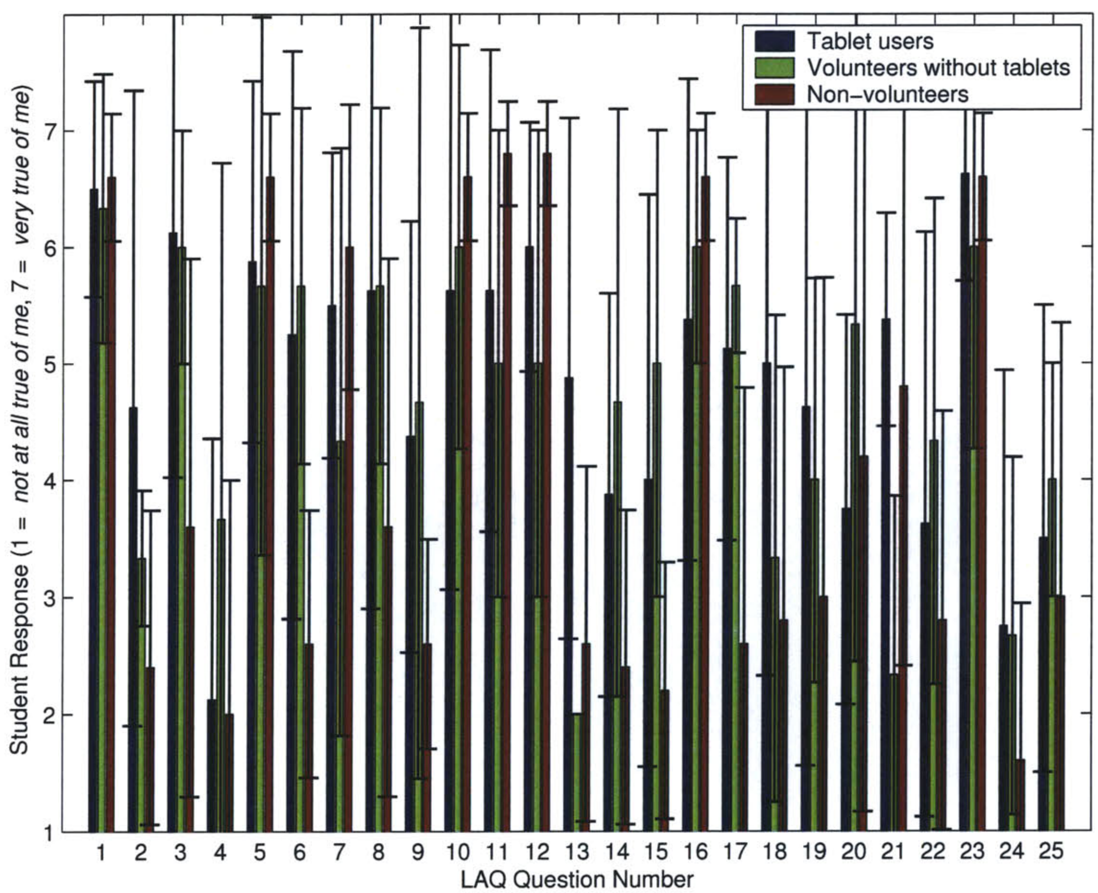


Figure B-10: Learning Attitudes Questionnaire (LAQ) Results—9.14, Spring 2003

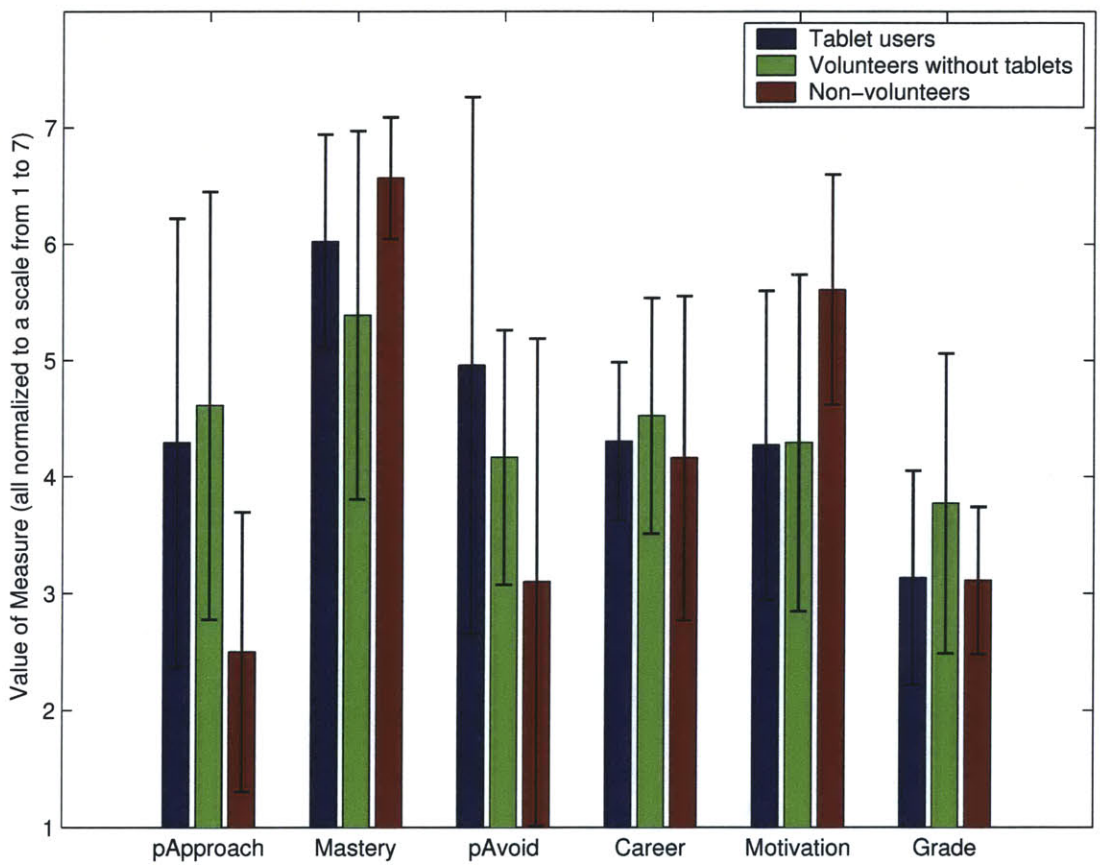


Figure B-11: Learning Attitudes Questionnaire (LAQ) Meta Results—9.14, Spring 2003

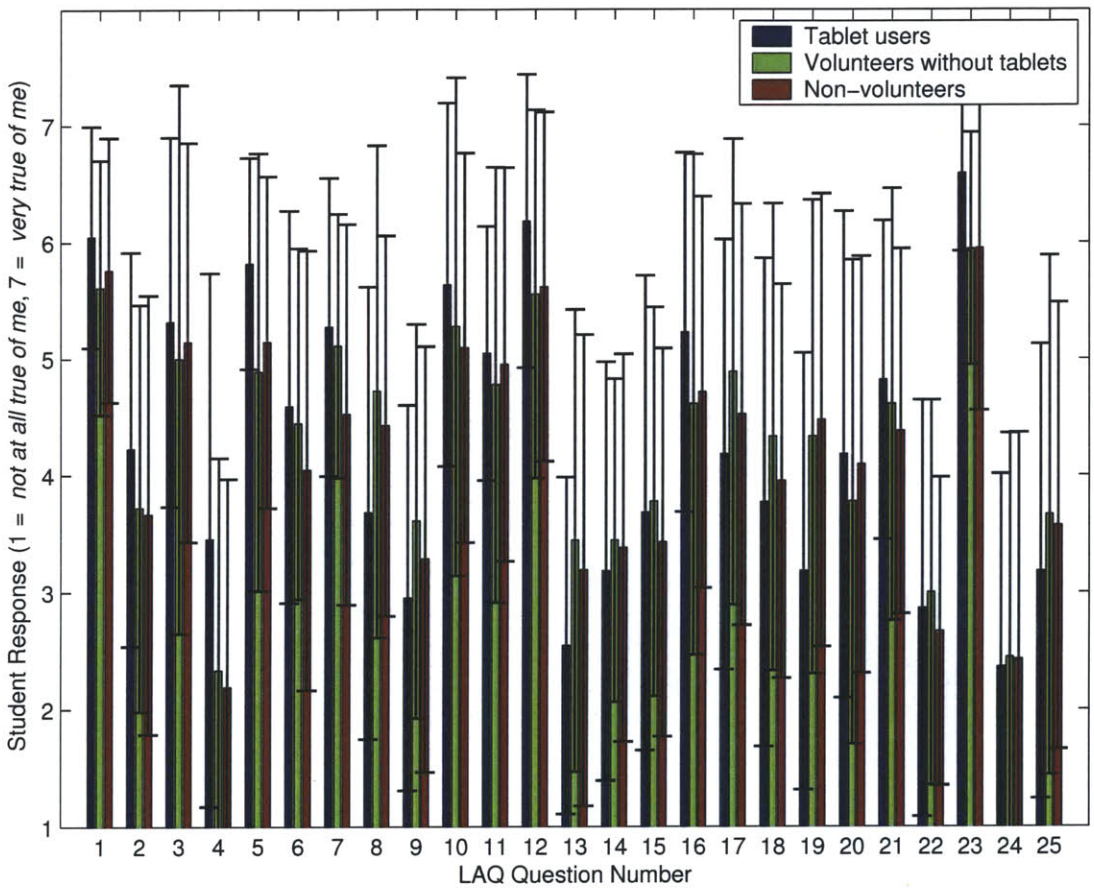


Figure B-12: Learning Attitudes Questionnaire (LAQ) Results—9.01, Fall 2003

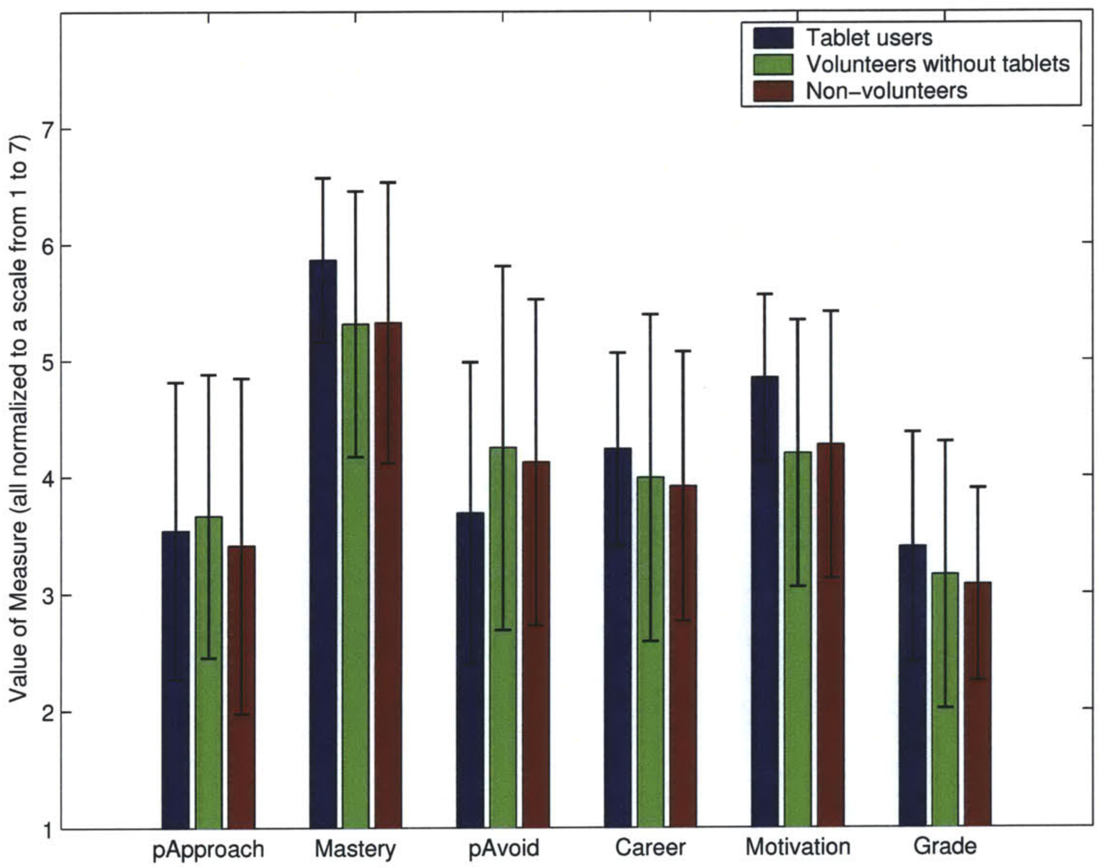


Figure B-13: Learning Attitudes Questionnaire (LAQ) Meta Results—9.01, Fall 2003

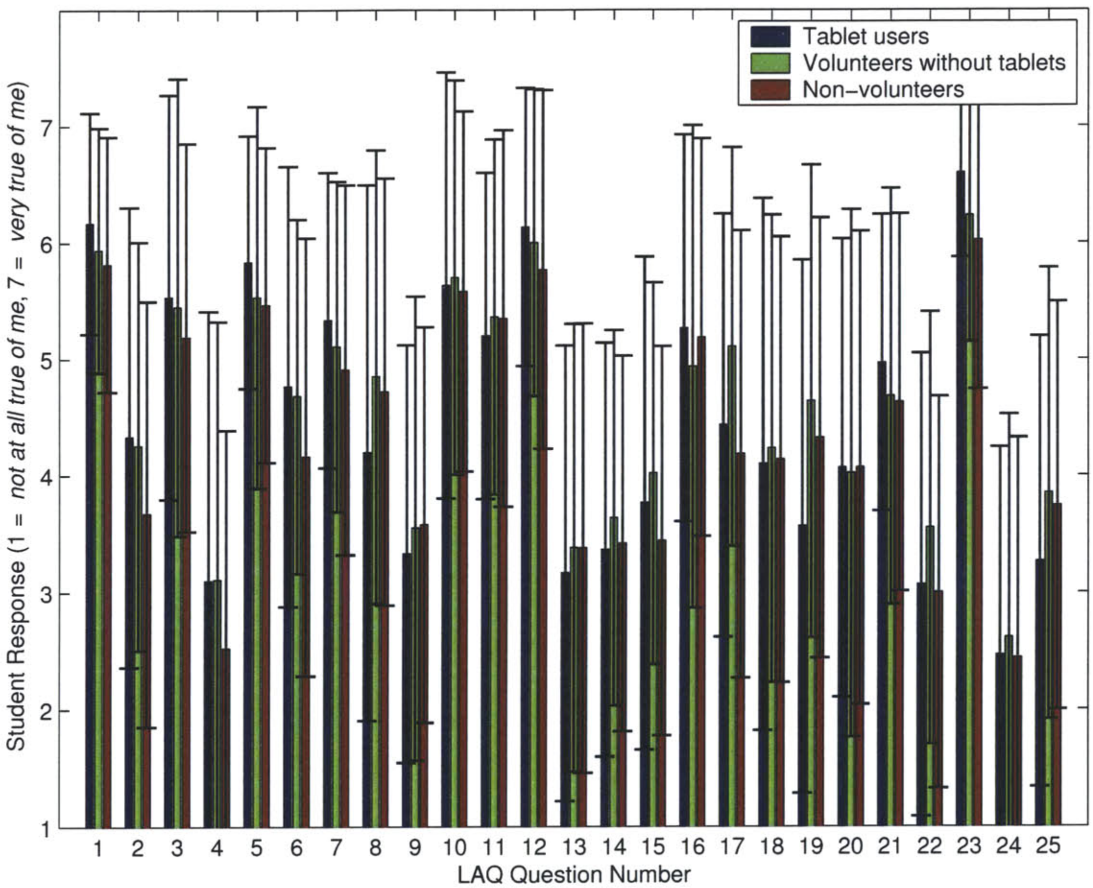


Figure B-14: Learning Attitudes Questionnaire (LAQ) Results—Aggregate

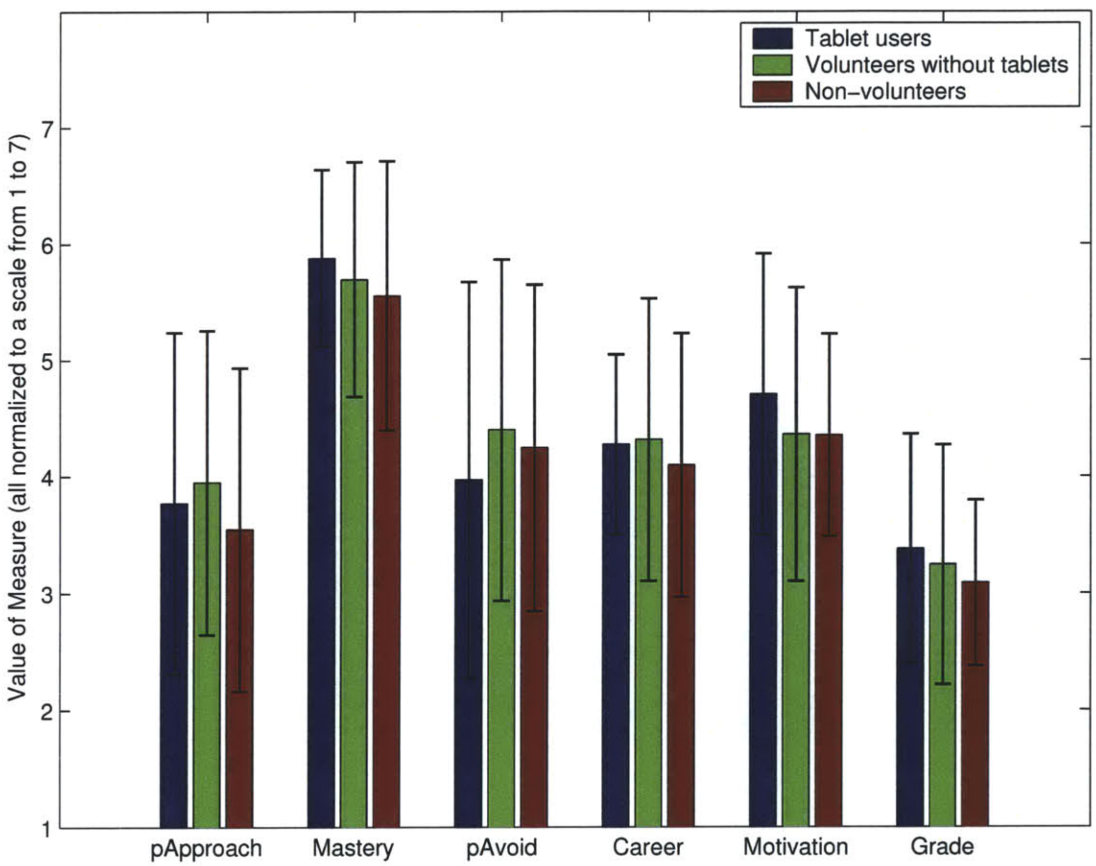


Figure B-15: Learning Attitudes Questionnaire (LAQ) Meta Results—Aggregate

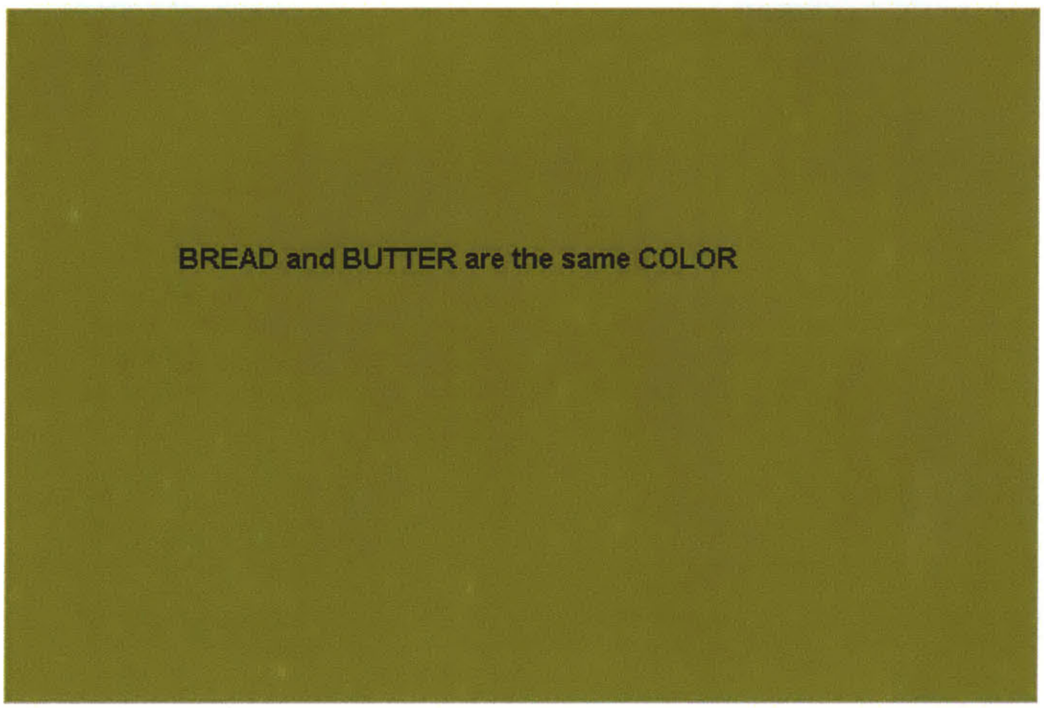


Figure B-16: A screenshot of the word section of the Cognitive Styles Analysis [40]

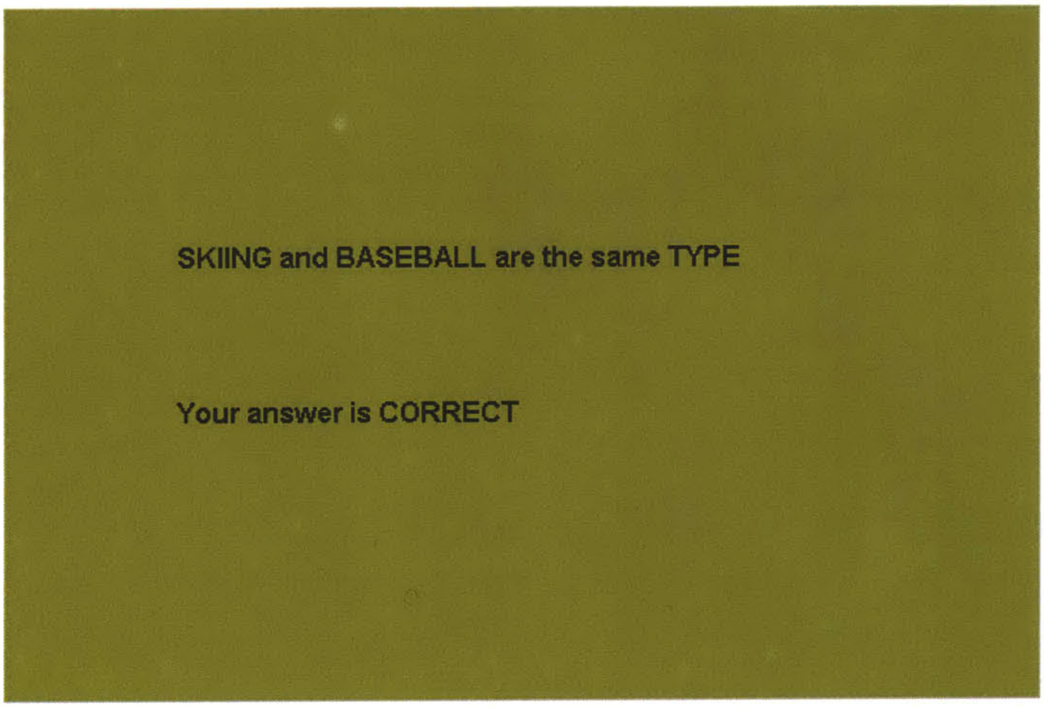


Figure B-17: Another screenshot of the word section of the Cognitive Styles Analysis [40]

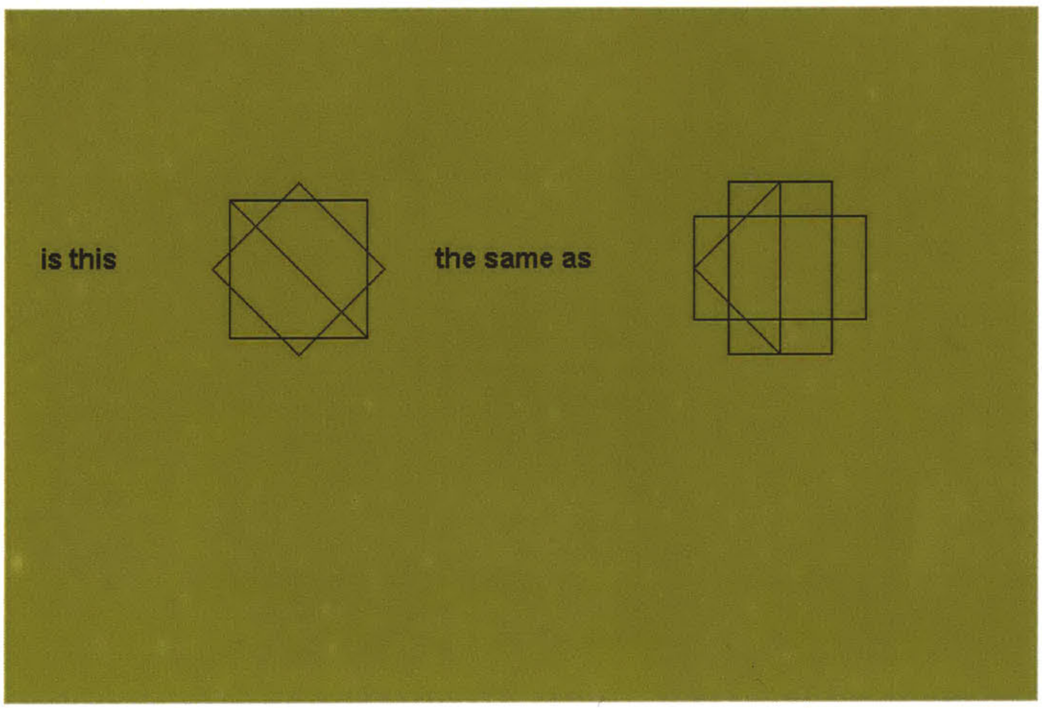


Figure B-18: A screenshot of the shape matching section of the Cognitive Styles Analysis [40]

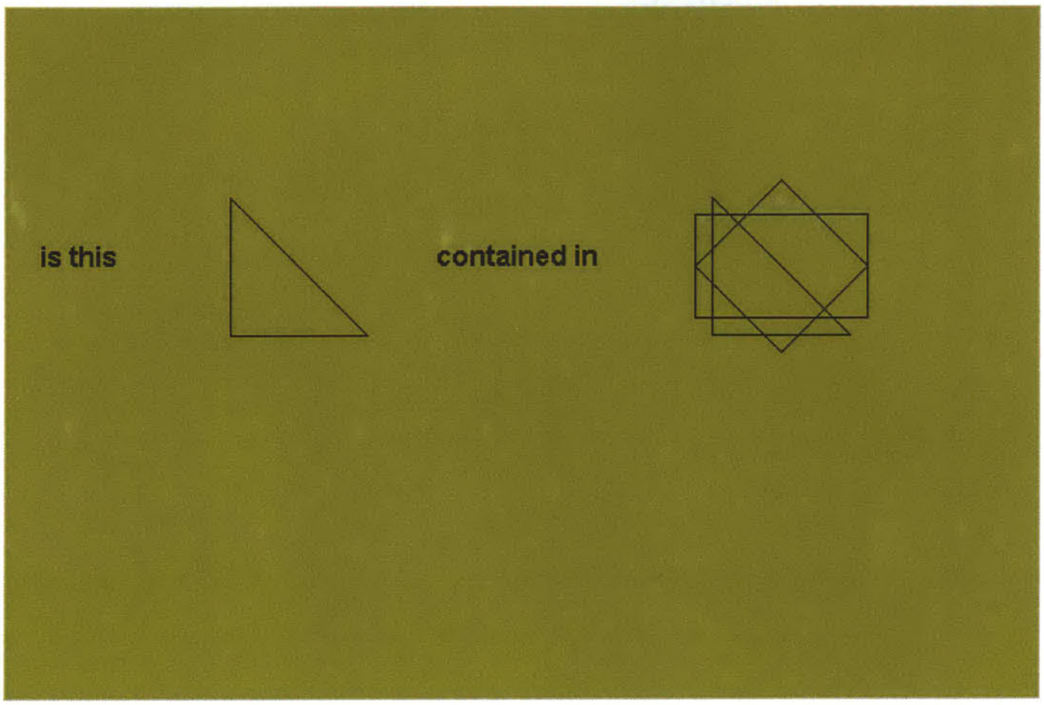


Figure B-19: A screenshot of the shape containment section of the Cognitive Styles Analysis [40]

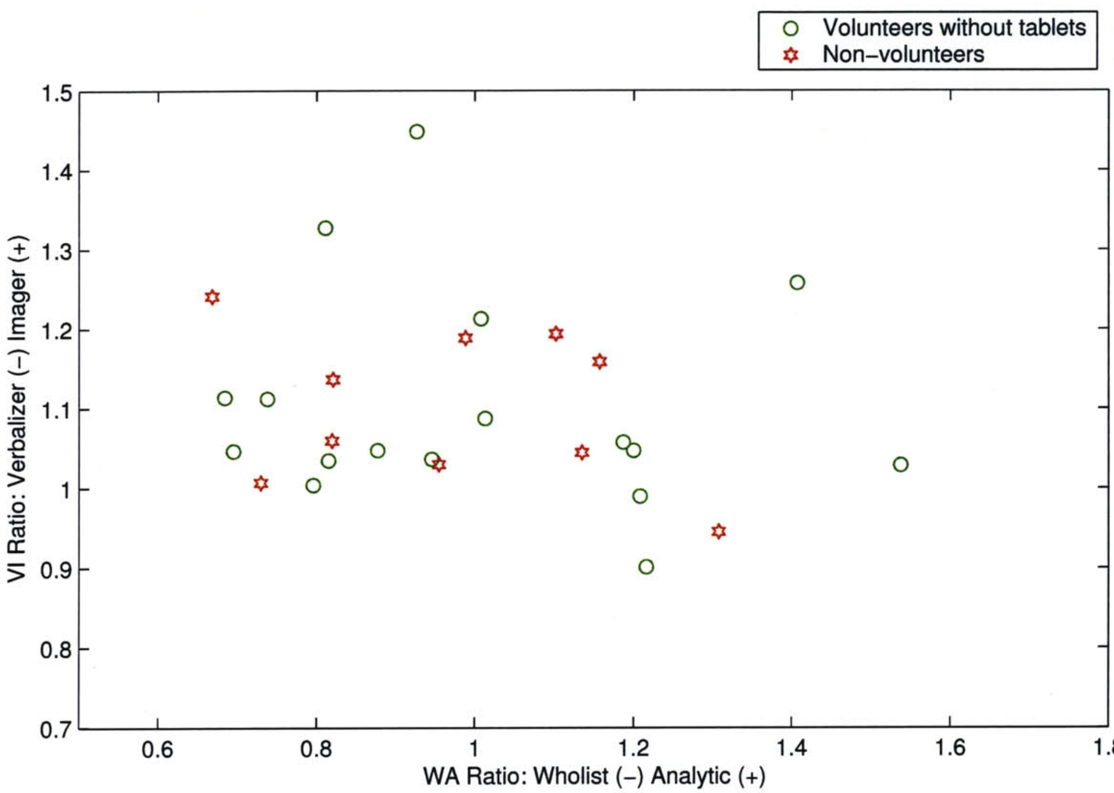


Figure B-20: Cognitive Styles Analysis (CSA) Results—9.01, Fall 2002

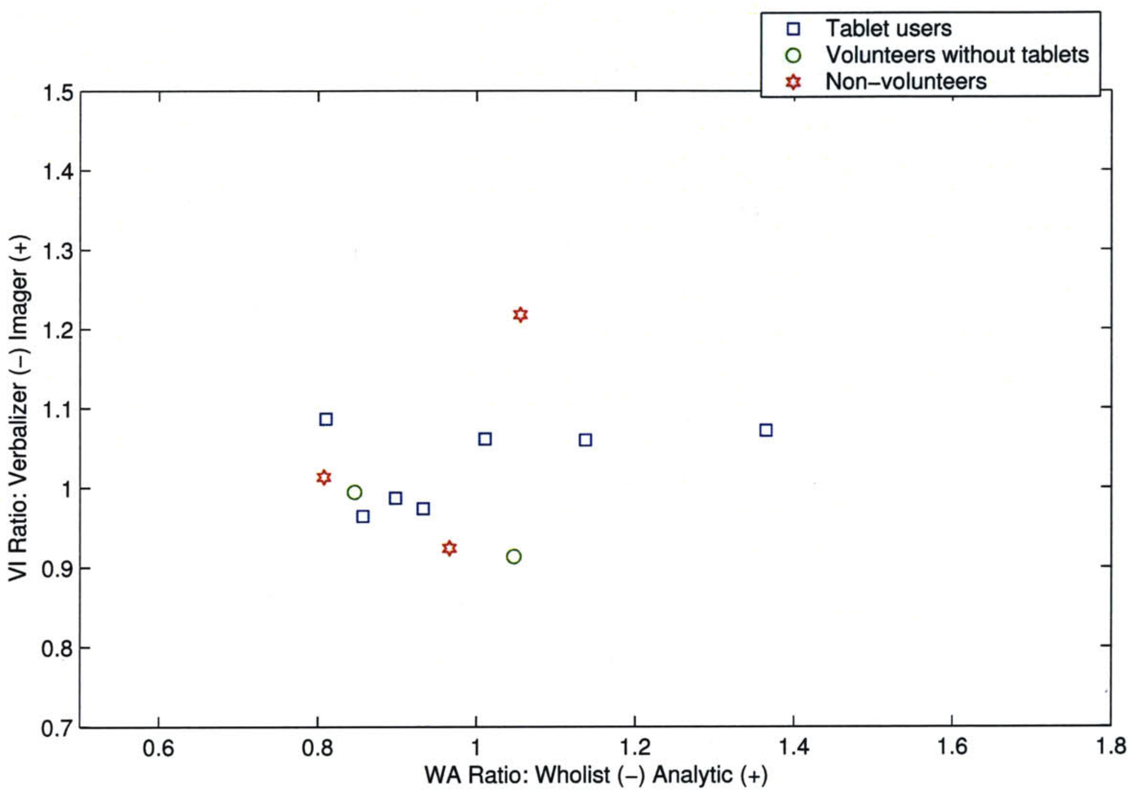


Figure B-21: Cognitive Styles Analysis (CSA) Results—9.14, Spring 2003

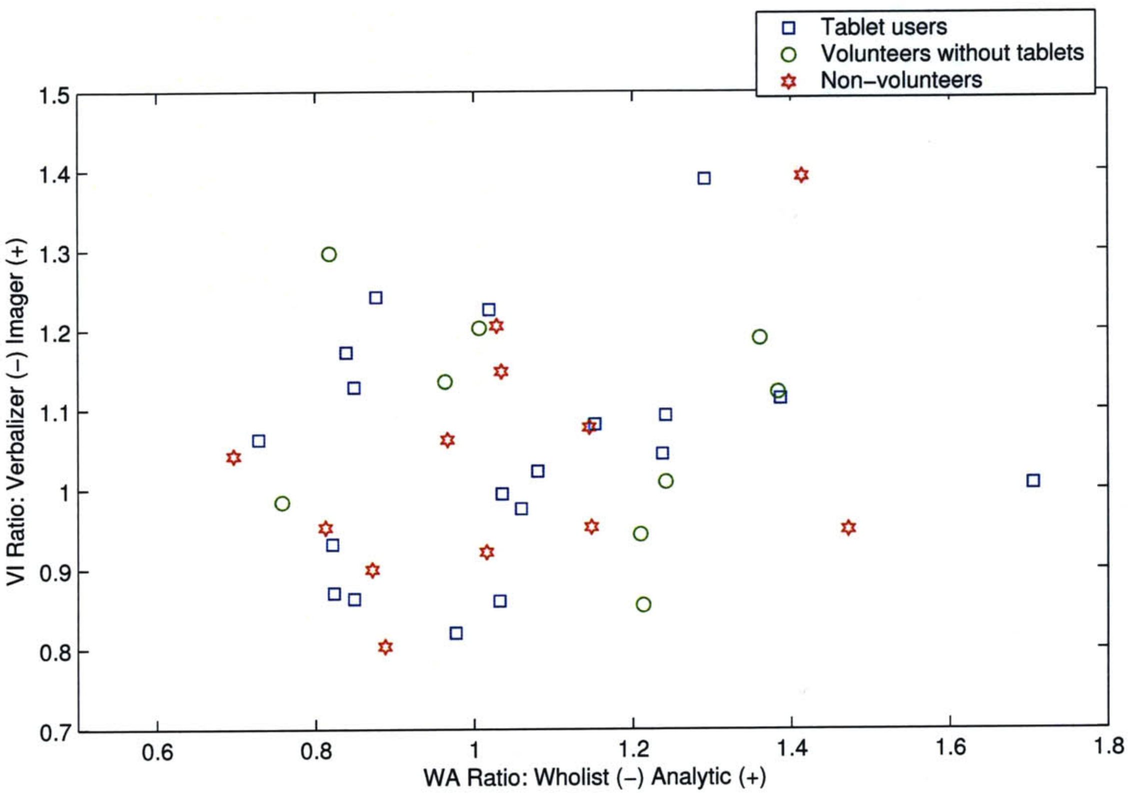


Figure B-22: Cognitive Styles Analysis (CSA) Results—9.01, Fall 2003

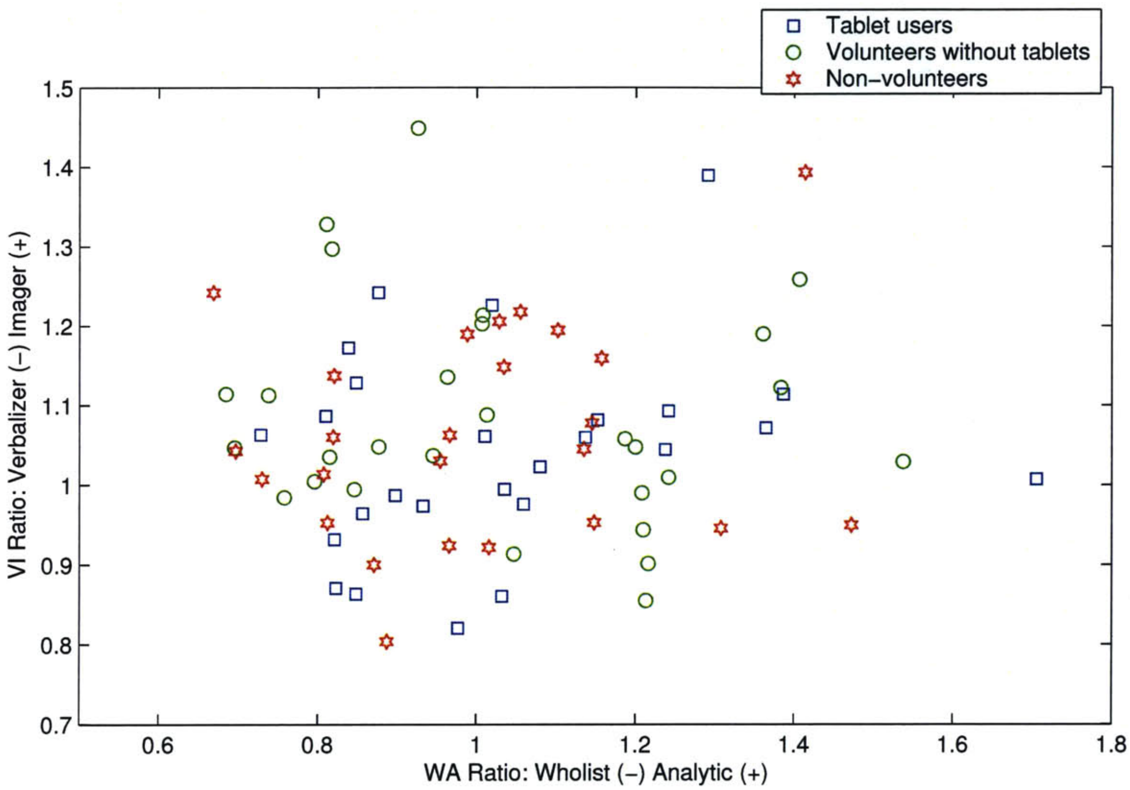


Figure B-23: Cognitive Styles Analysis (CSA) Results—Aggregate

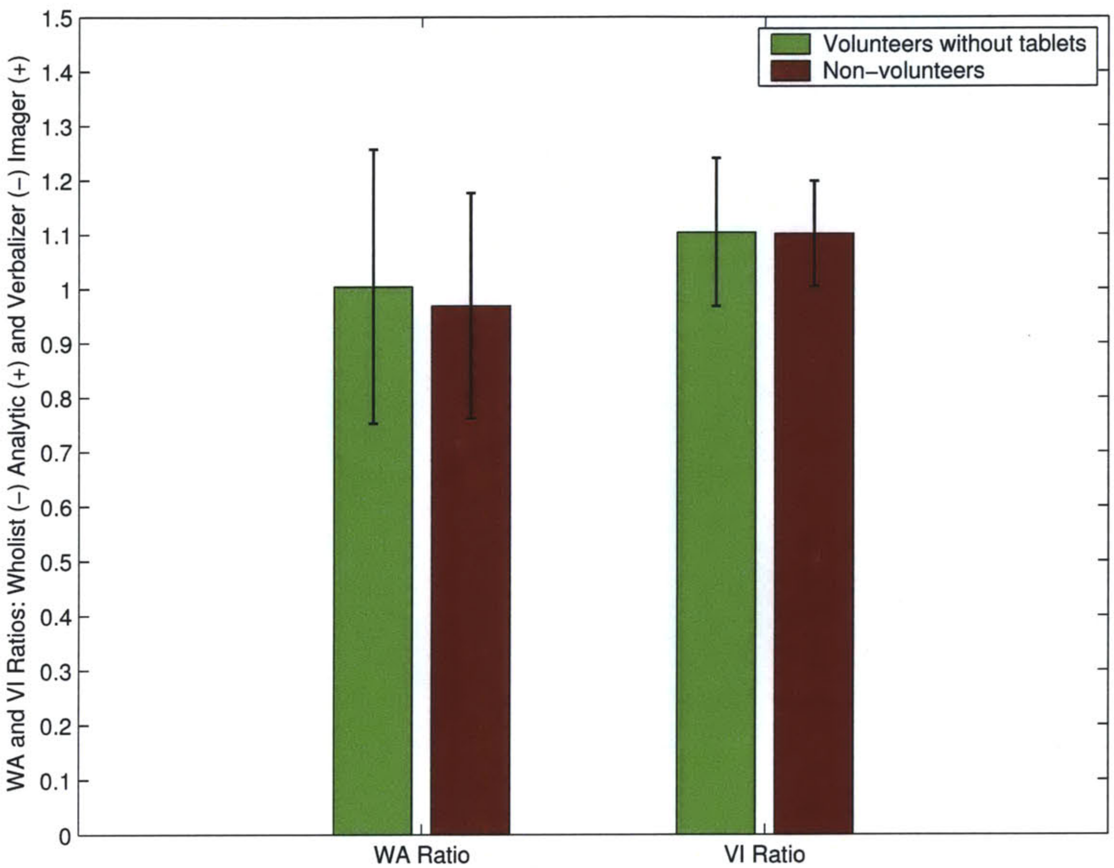


Figure B-24: Cognitive Styles Analysis (CSA) Means by Group—9.01, Fall 2002

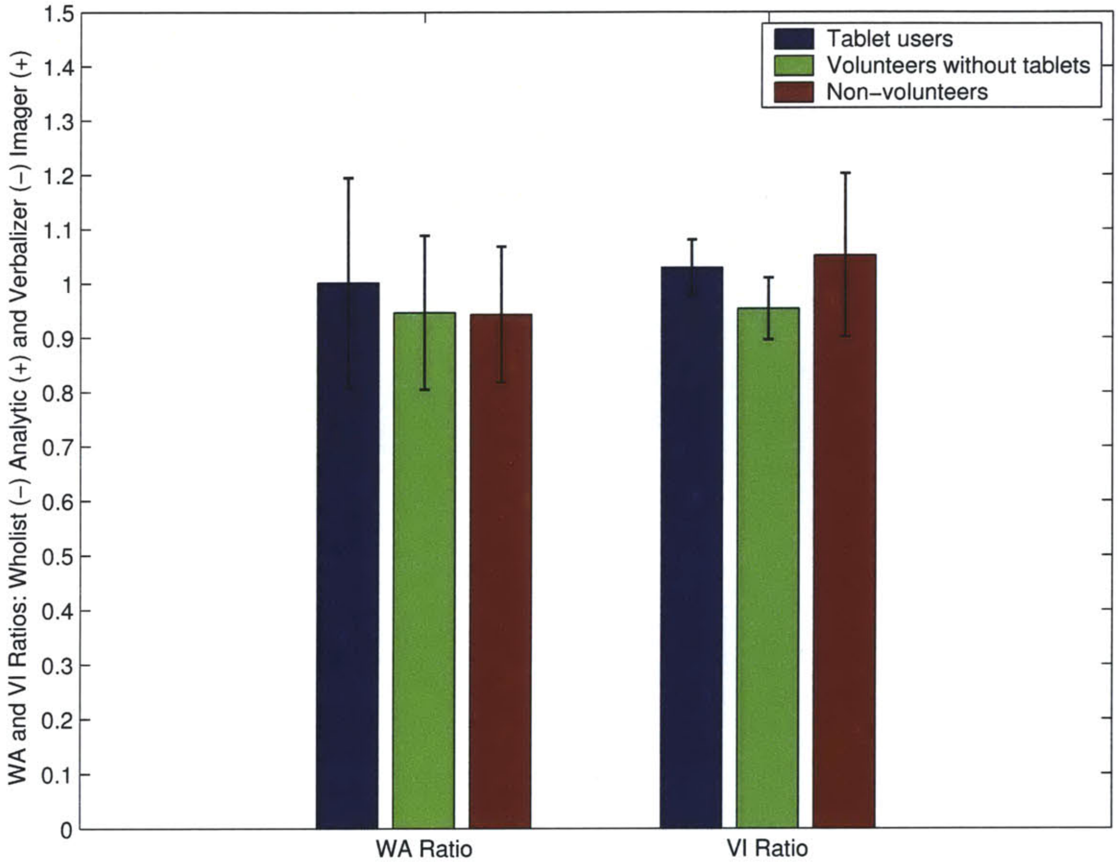


Figure B-25: Cognitive Styles Analysis (CSA) Means by Group—9.14, Spring 2003

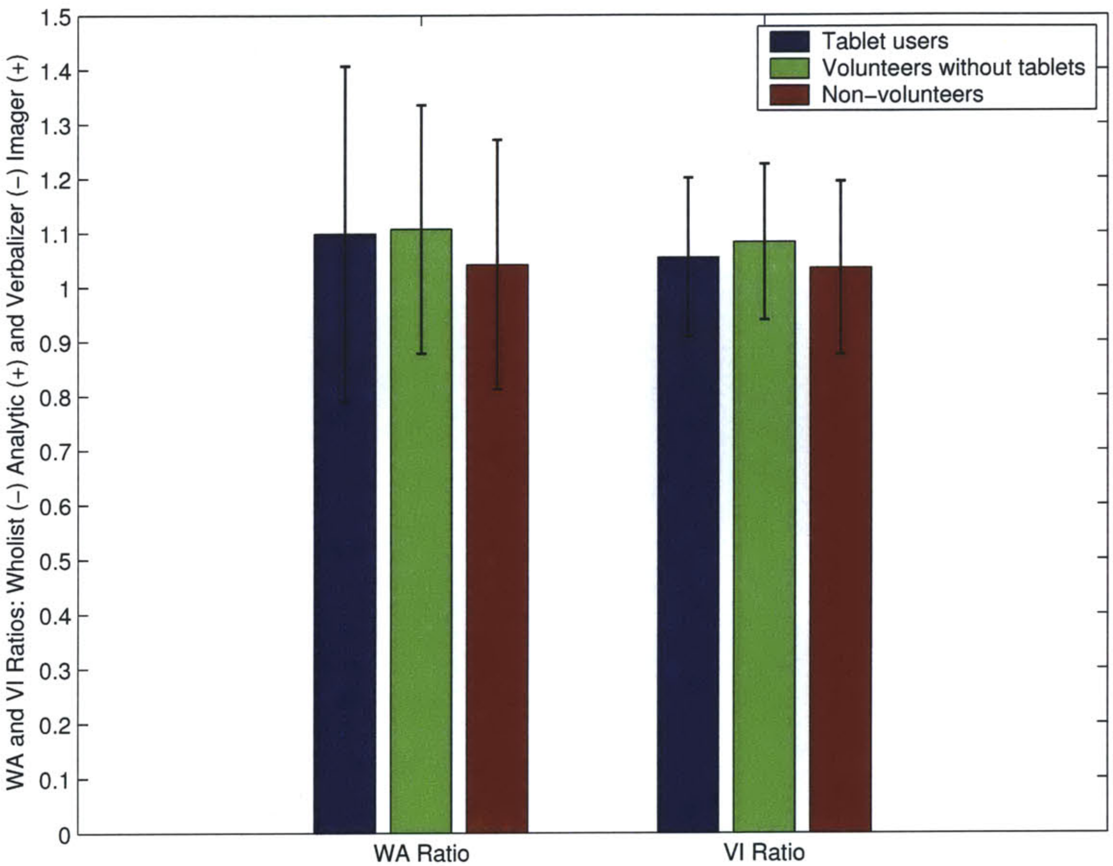


Figure B-26: Cognitive Styles Analysis (CSA) Means by Group—9.01, Fall 2003

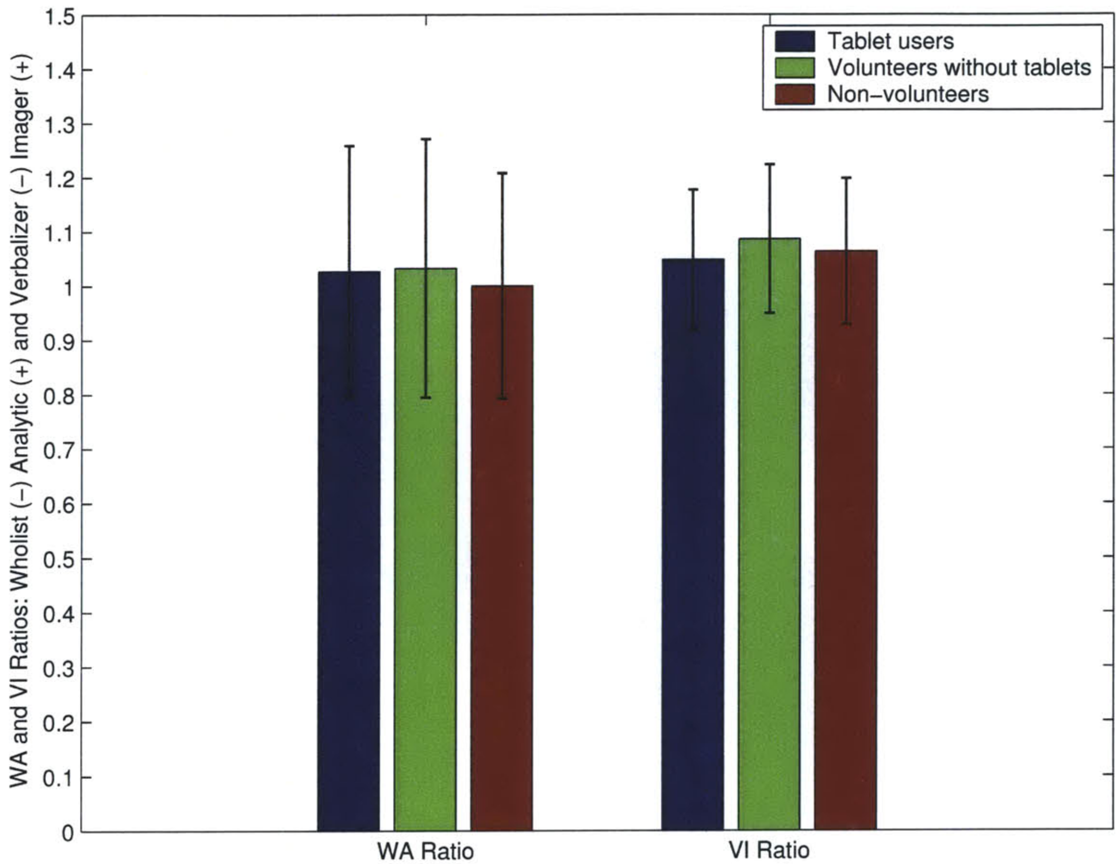


Figure B-27: Cognitive Styles Analysis (CSA) Means by Group—Aggregate

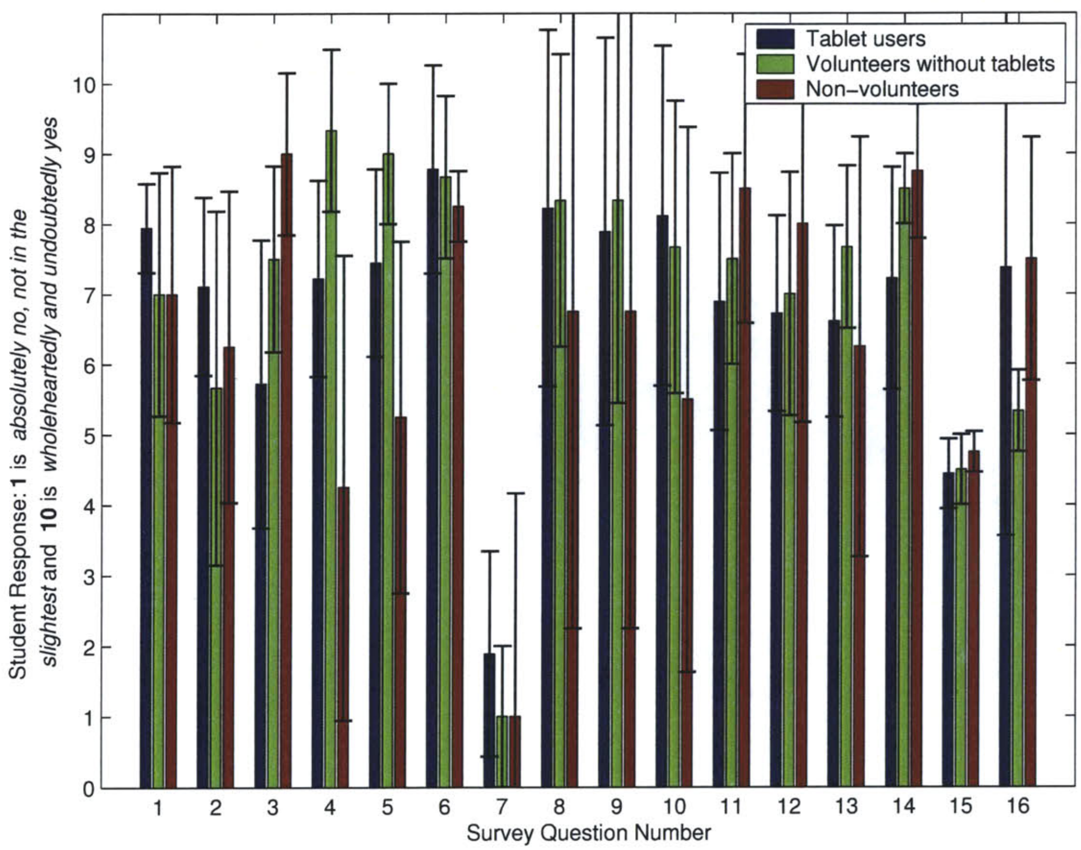


Figure B-28: Matched Survey Results—Beginning of Term, 9.14, Spring 2003

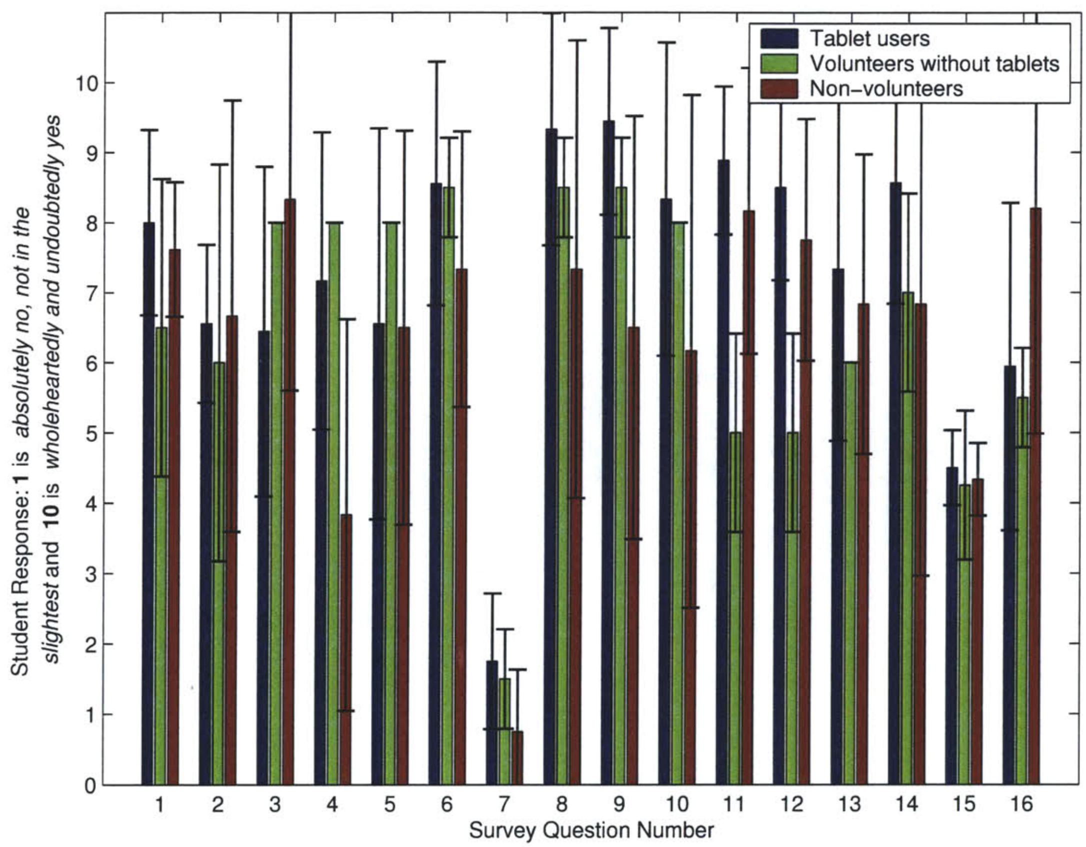


Figure B-29: Matched Survey Results—End of Term, 9.14, Spring 2003

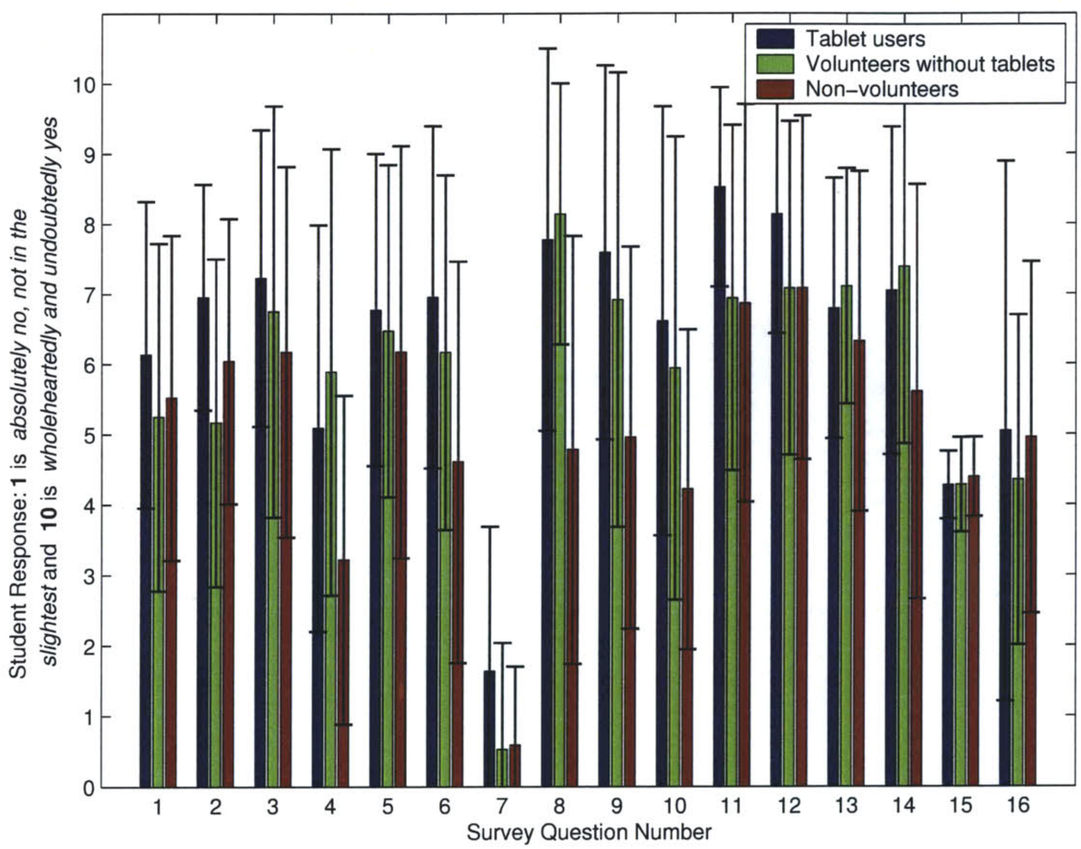


Figure B-30: Matched Survey Results—End of Term, 9.01, Fall 2003

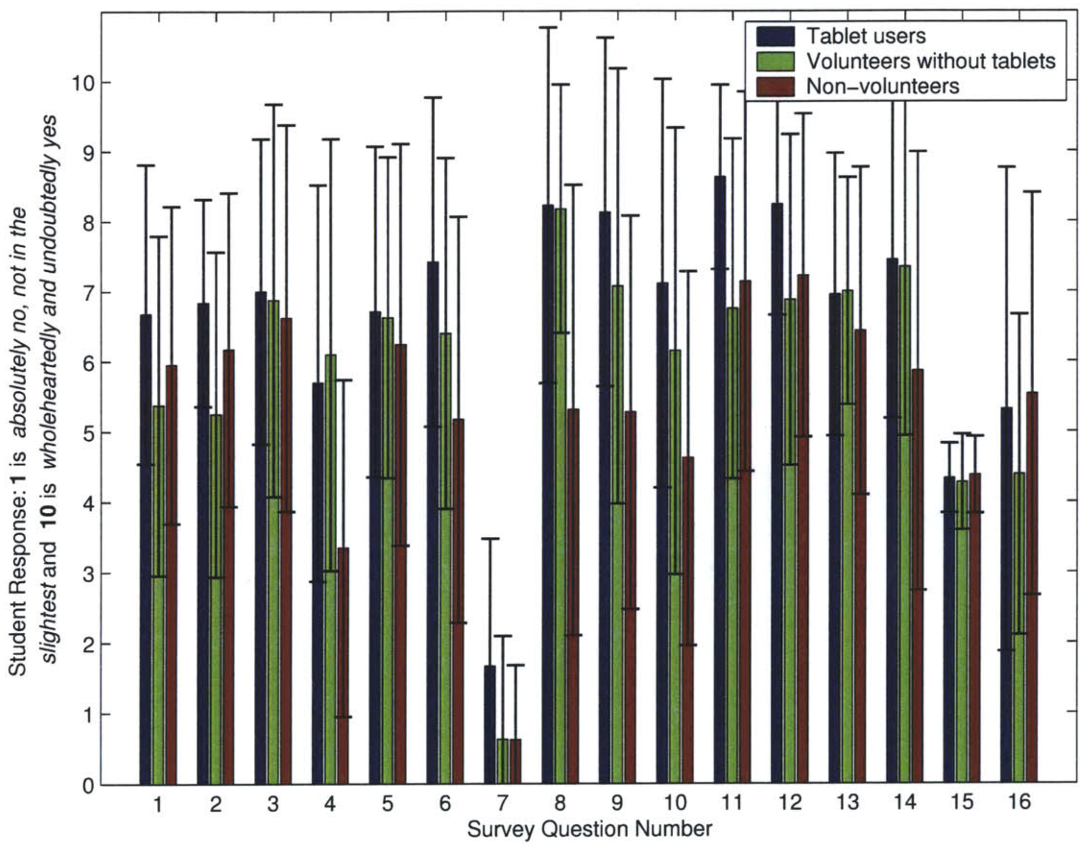


Figure B-31: Matched Survey Results—End of Term, Aggregate

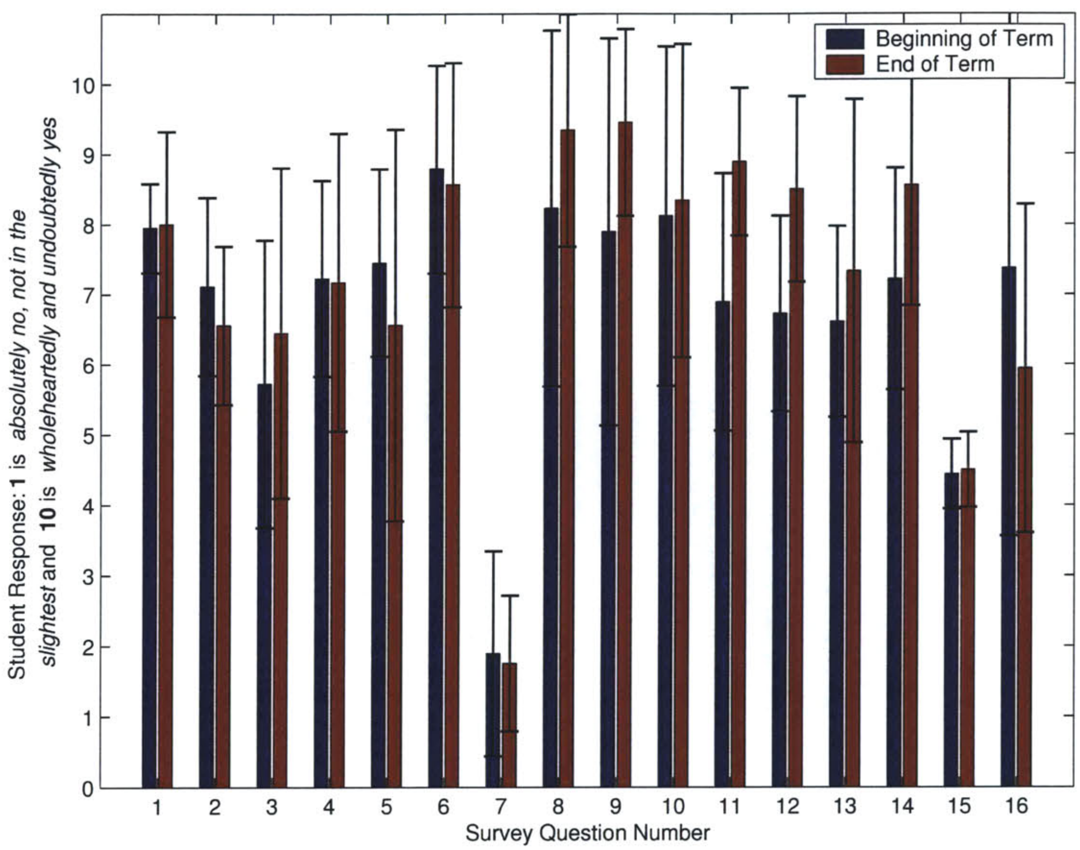


Figure B-32: Matched Survey Results—Start and End of Term Comparison, Tablet Users

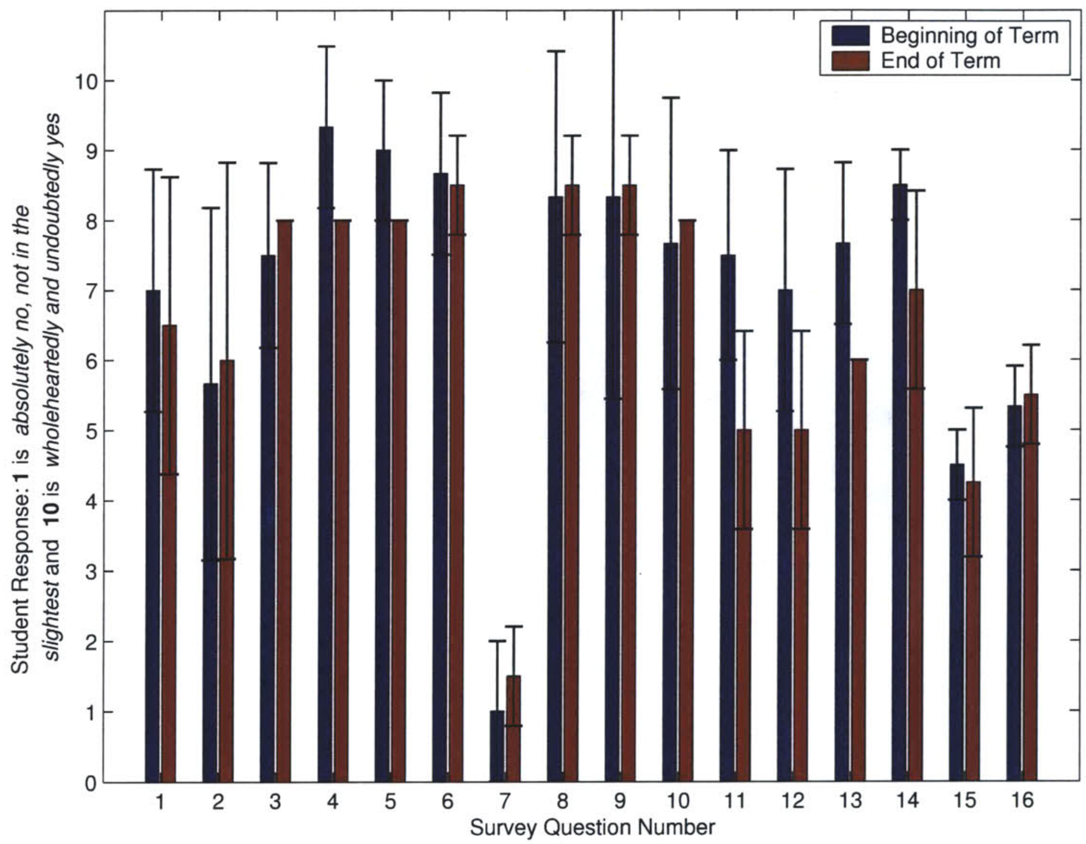


Figure B-33: Matched Survey Results—Start and End of Term Comparison, Volunteers without Tablets

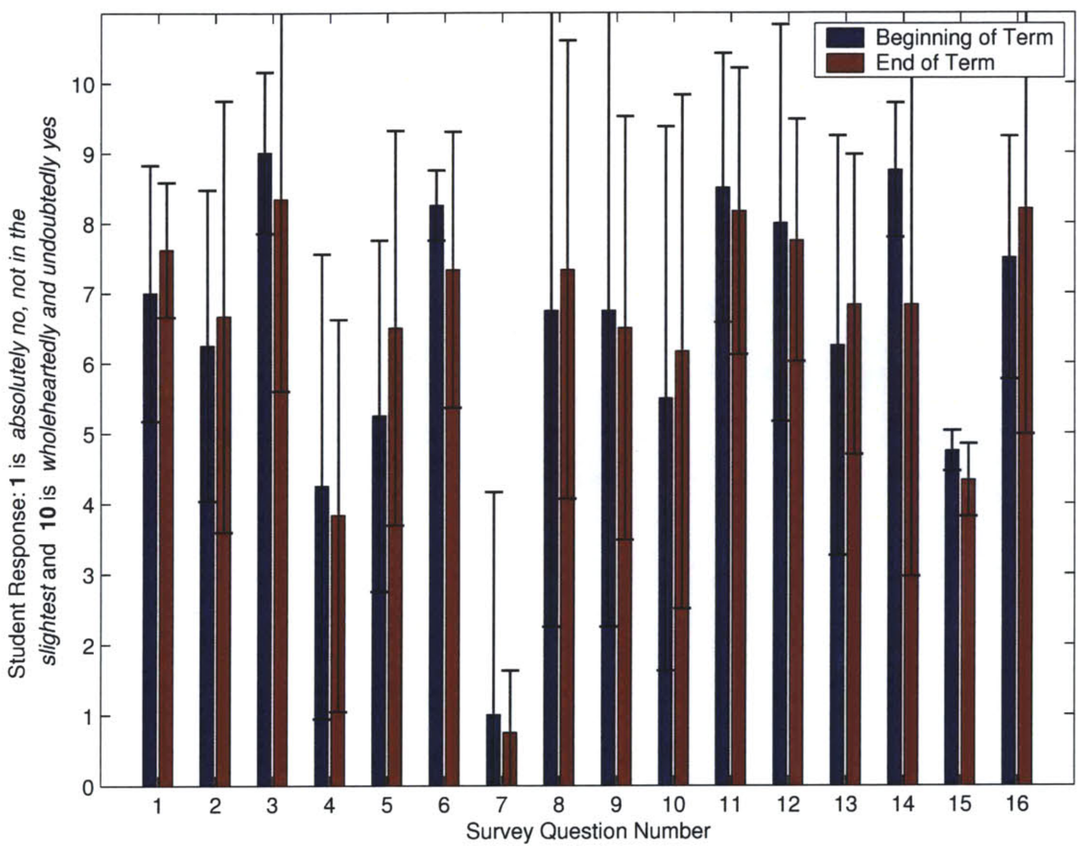


Figure B-34: Matched Survey Results—Start and End of Term Comparison, Non-Volunteers

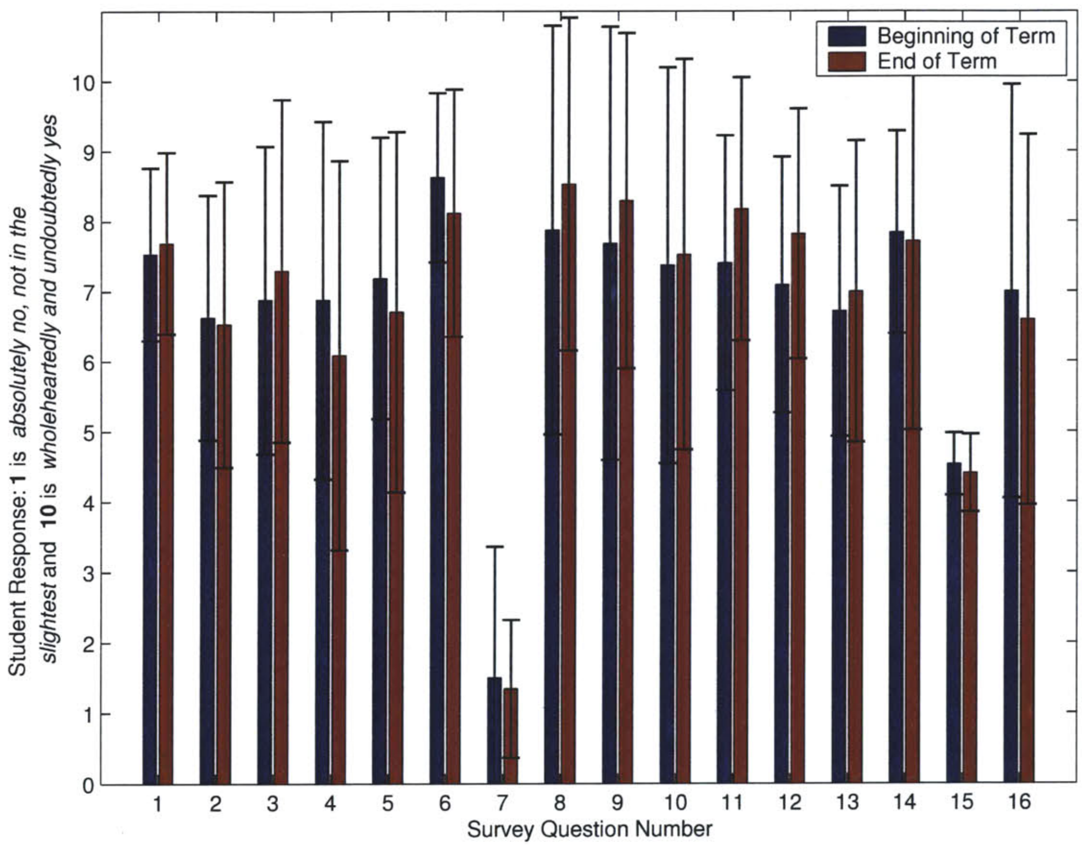


Figure B-35: Matched Survey Results—Start and End of Term Comparison, All Students

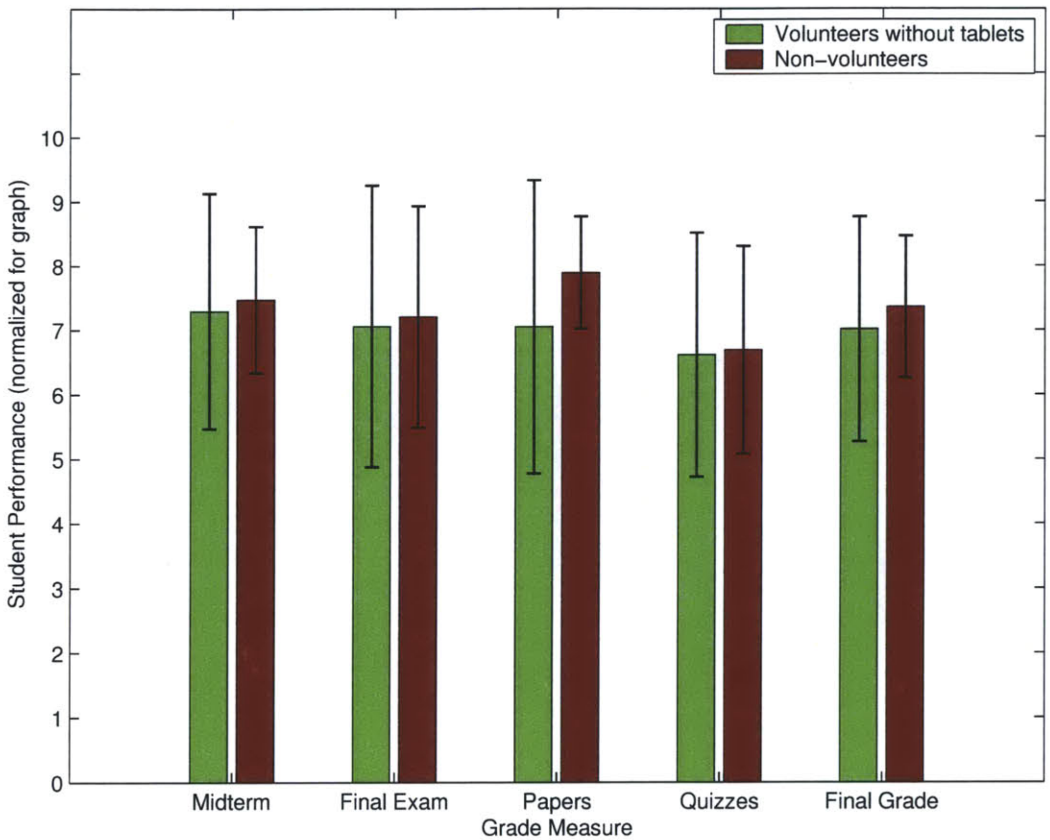


Figure B-36: Student Grade Data—9.01, Fall 2002

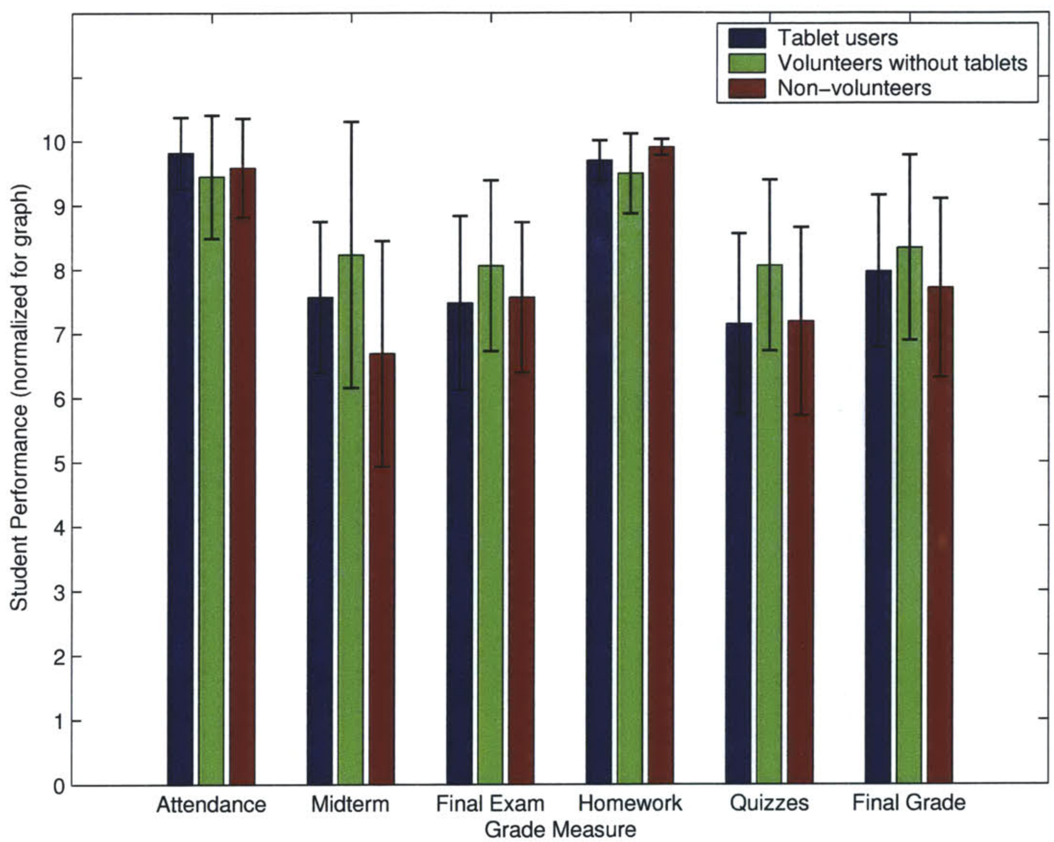


Figure B-37: Student Grade Data—9.14, Spring 2003

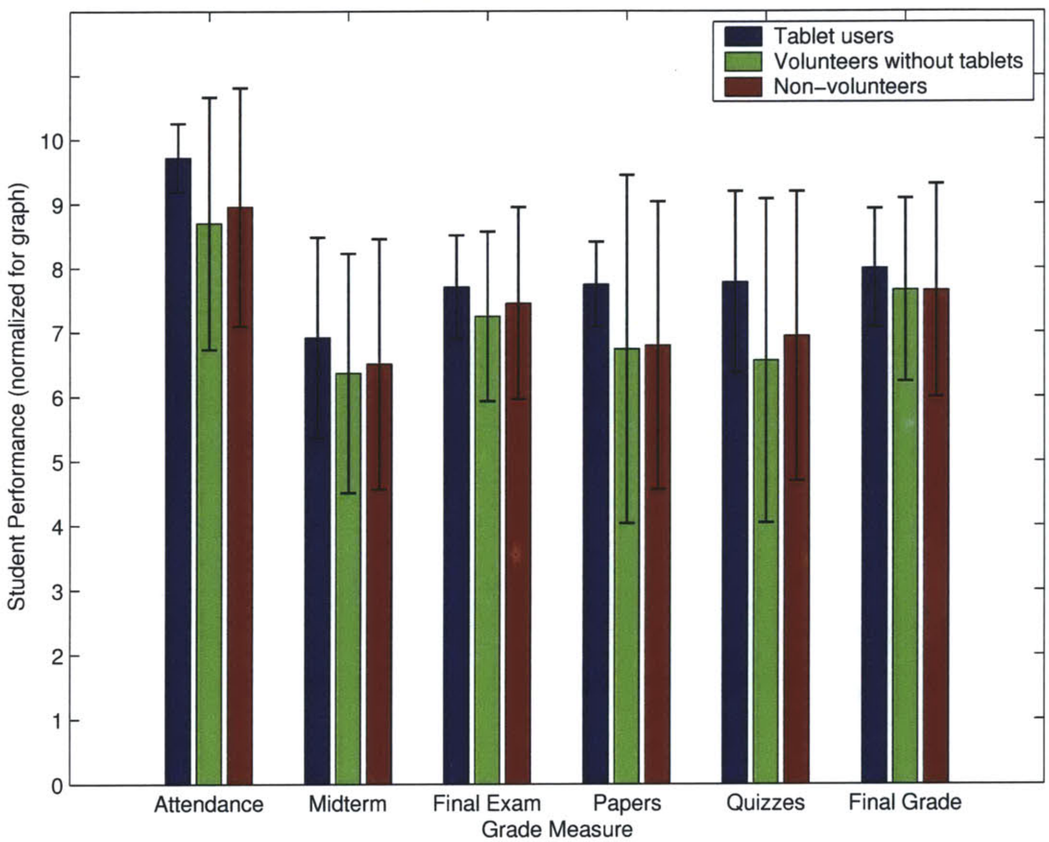


Figure B-38: Student Grade Data—9.01, Fall 2003

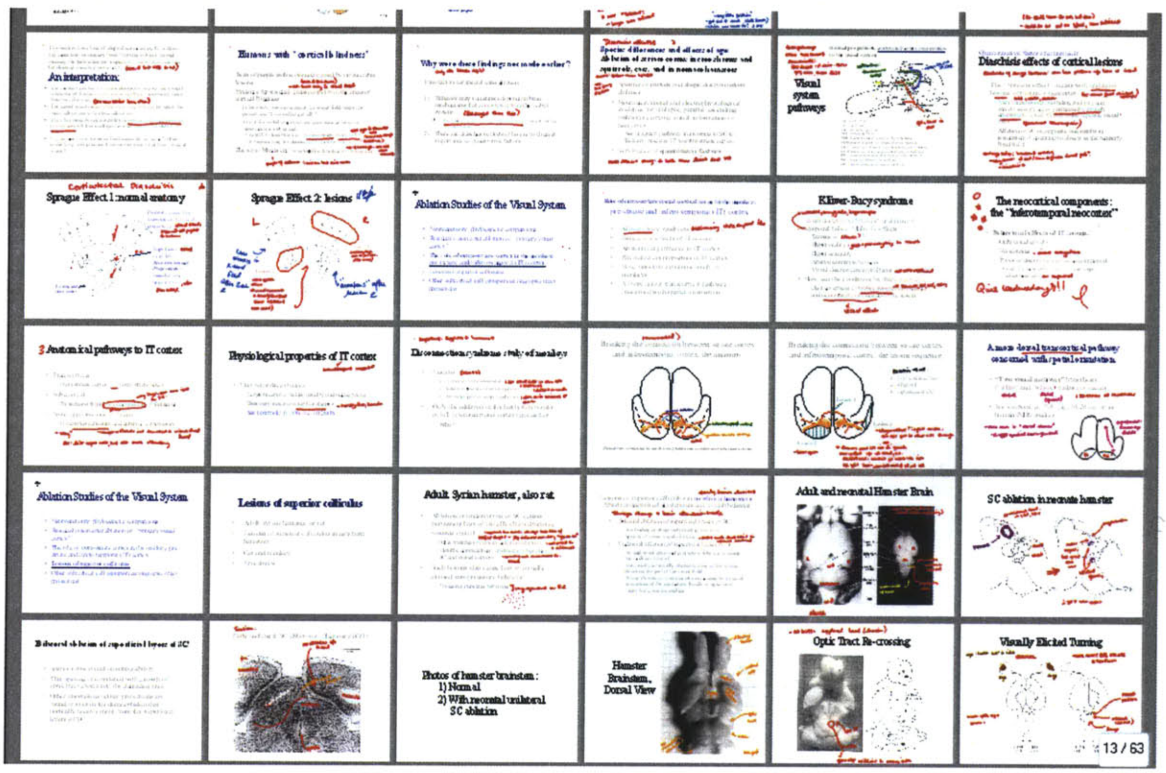


Figure B-39: Example Student Notes—A high-level view of one student's notes [34] [46]

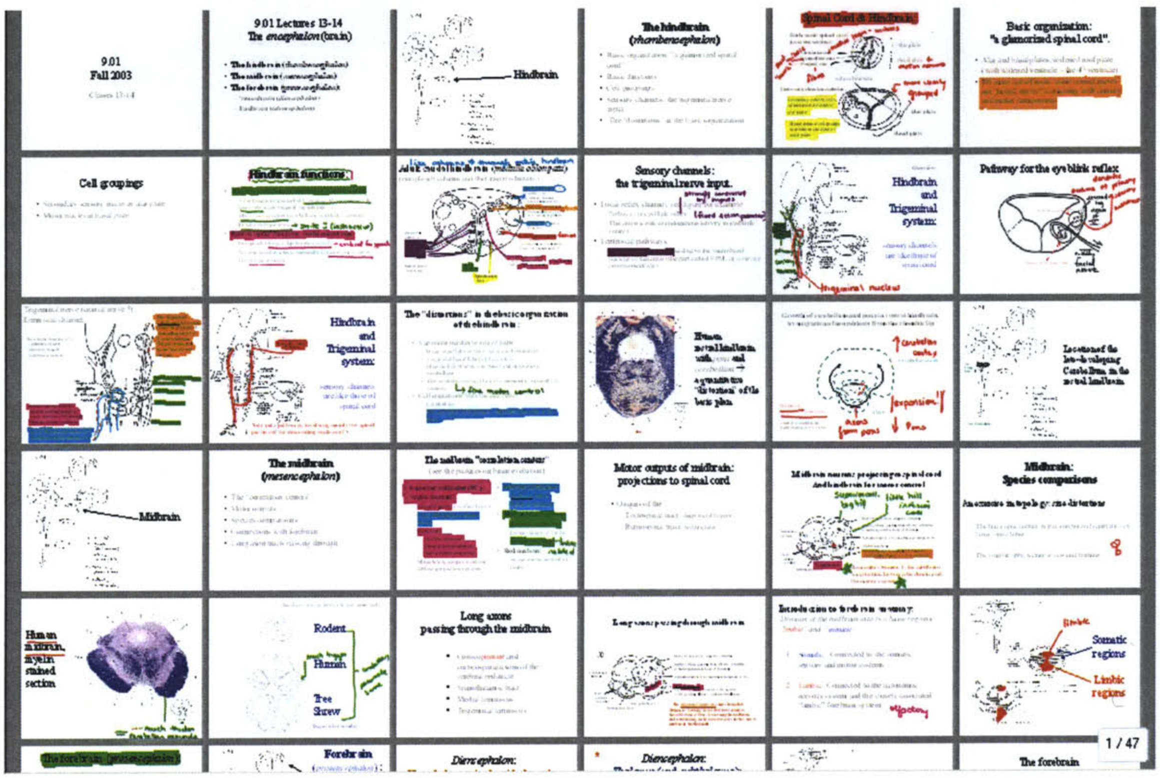


Figure B-40: Example Student Notes—A high-level view of another student's notes [34] [46] [36]

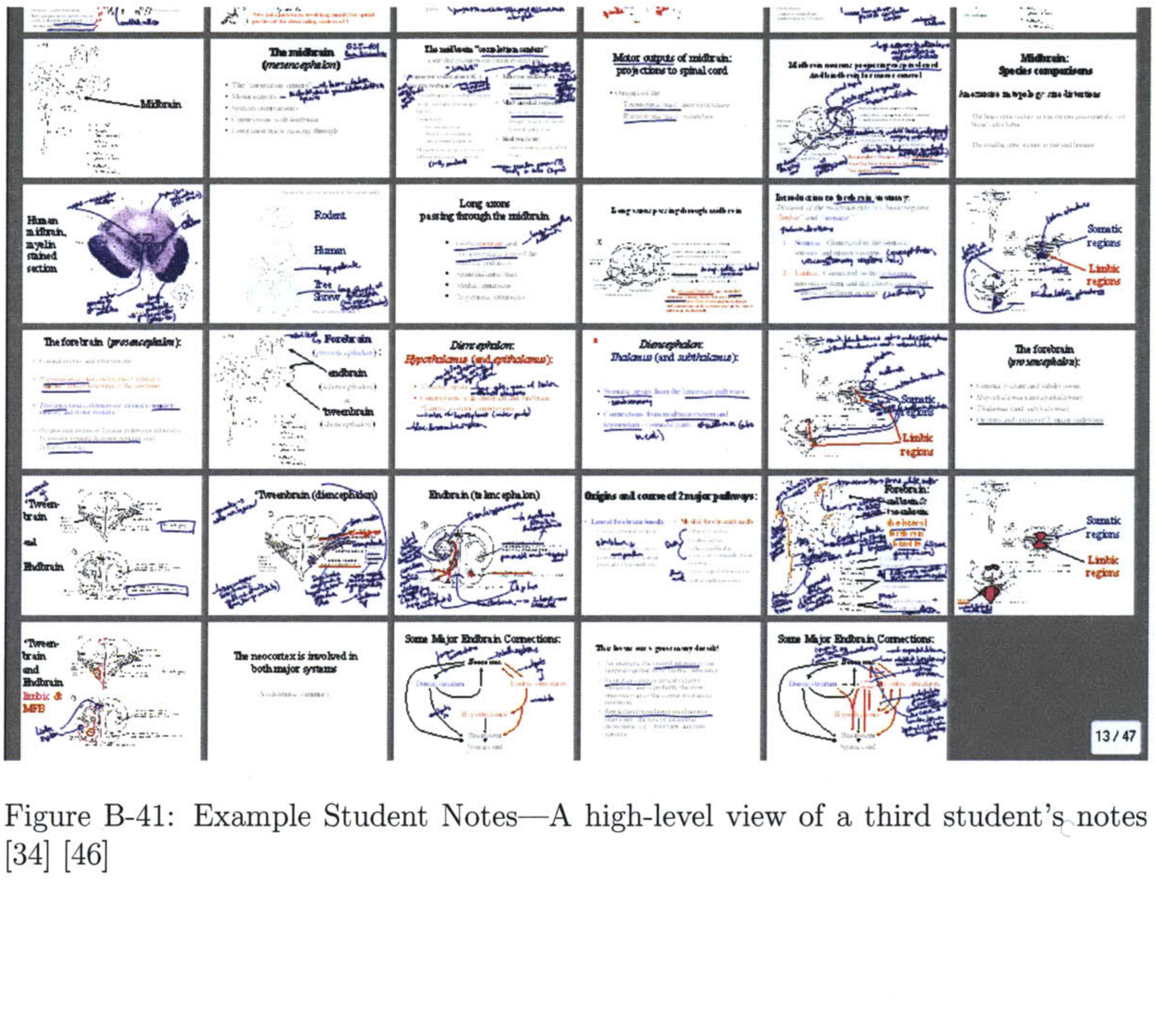


Figure B-41: Example Student Notes—A high-level view of a third student's notes [34] [46]

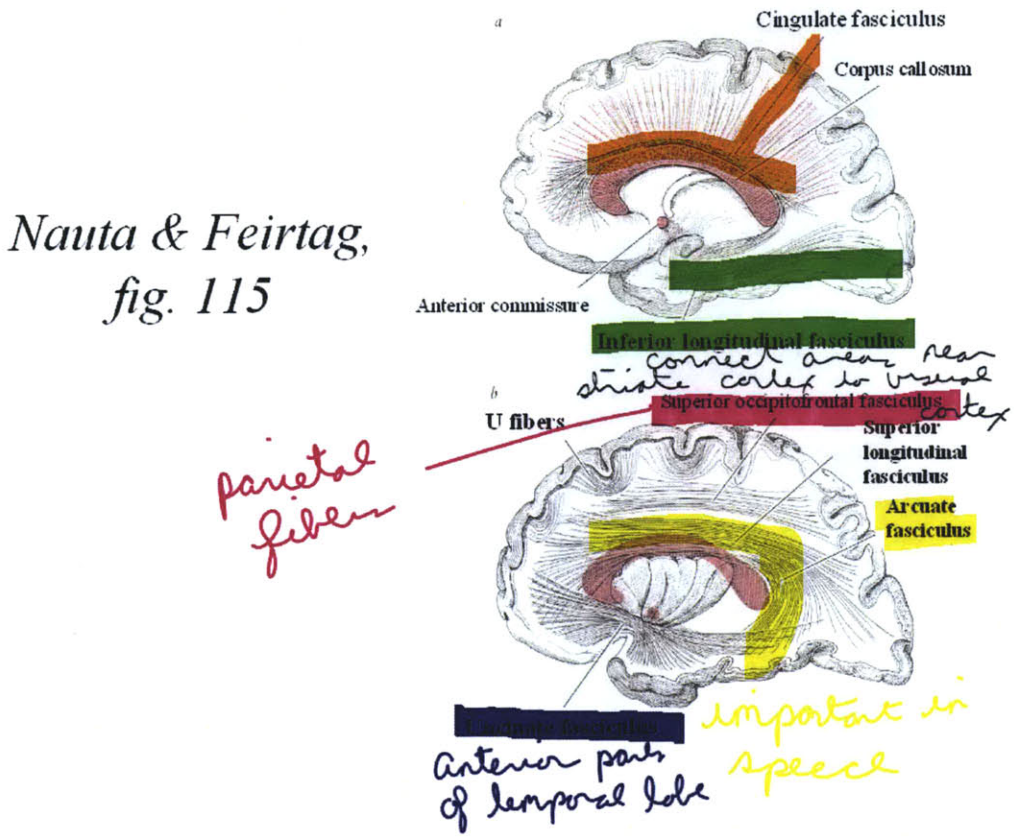


Figure B-42: Example Student Notes—A student makes use of color [34]

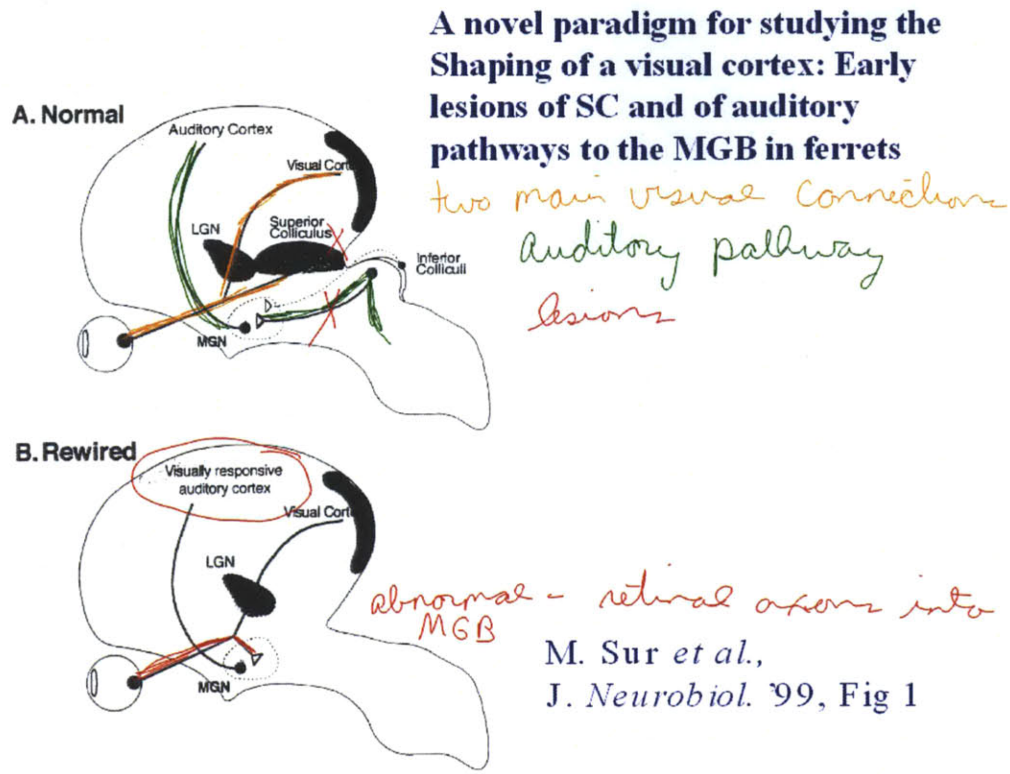


Figure B-43: Example Student Notes—A student makes use of color [52]

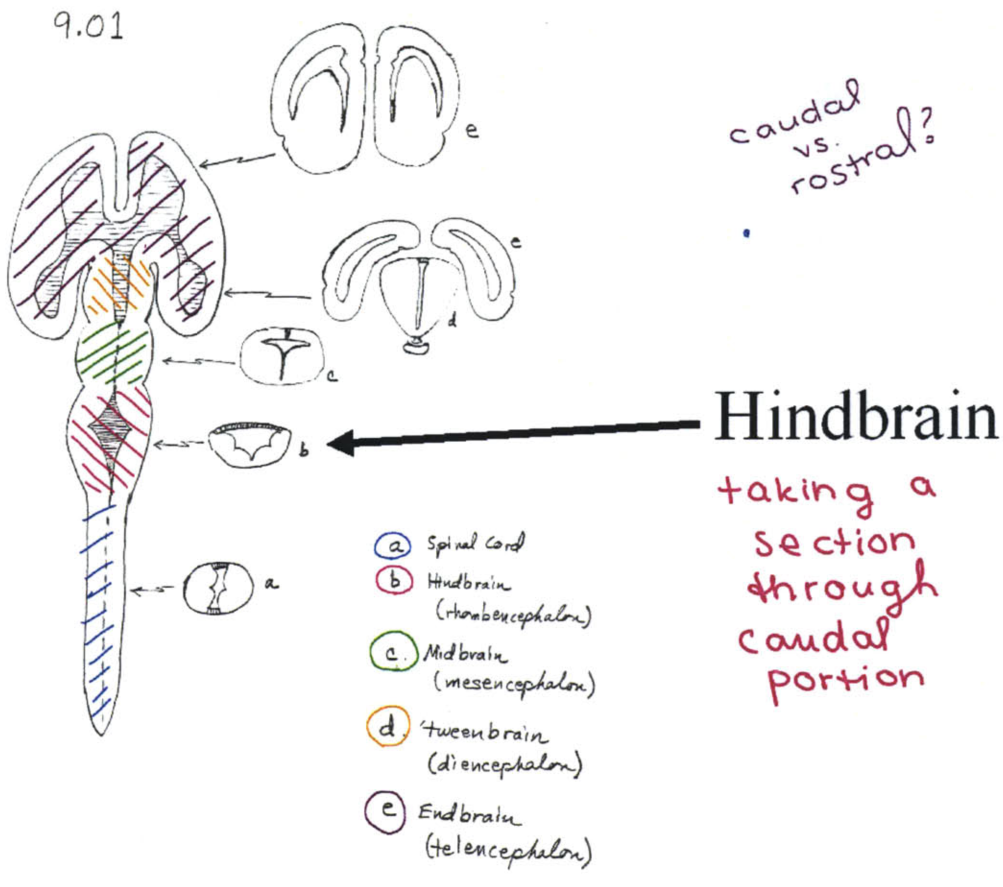


Figure B-44: Example Student Notes—A student makes use of color [46]

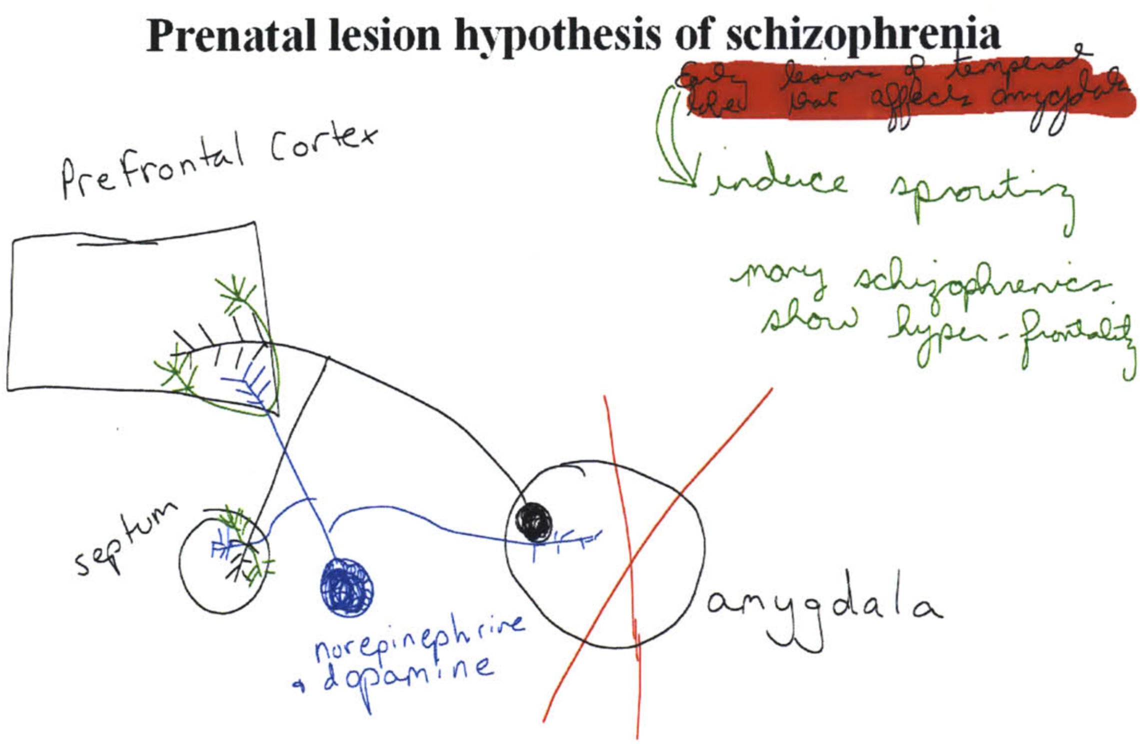


Figure B-45: Example Student Notes—A student creates a diagram along with the Professor

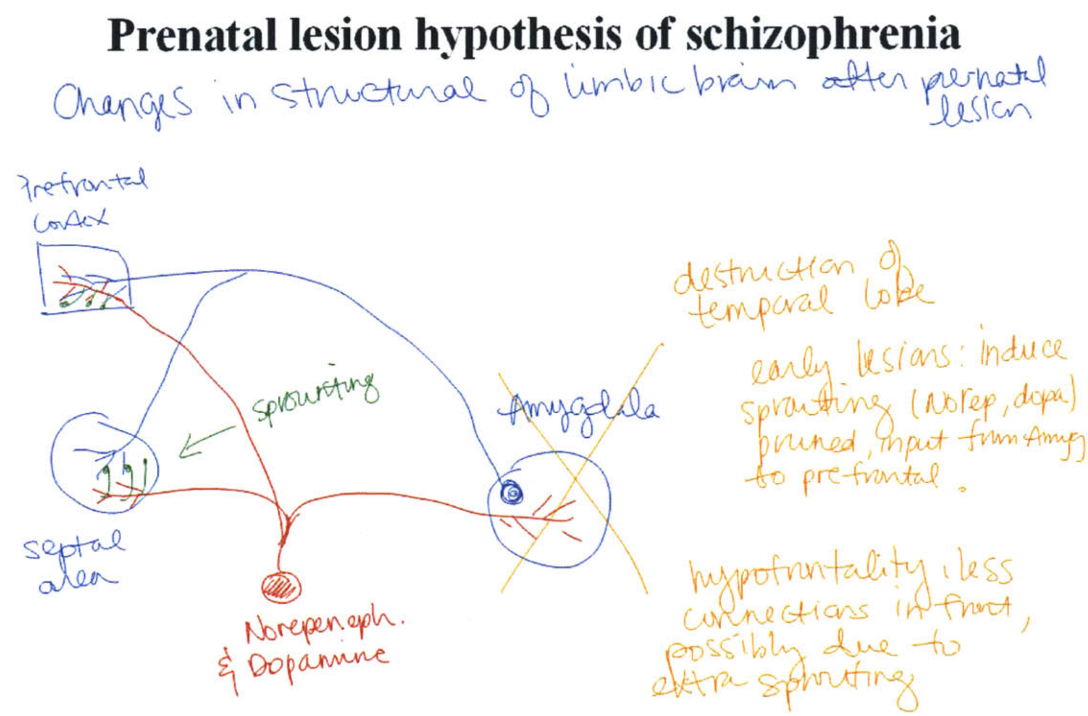


Figure B-46: Example Student Notes—Another student creates the same diagram along with the Professor

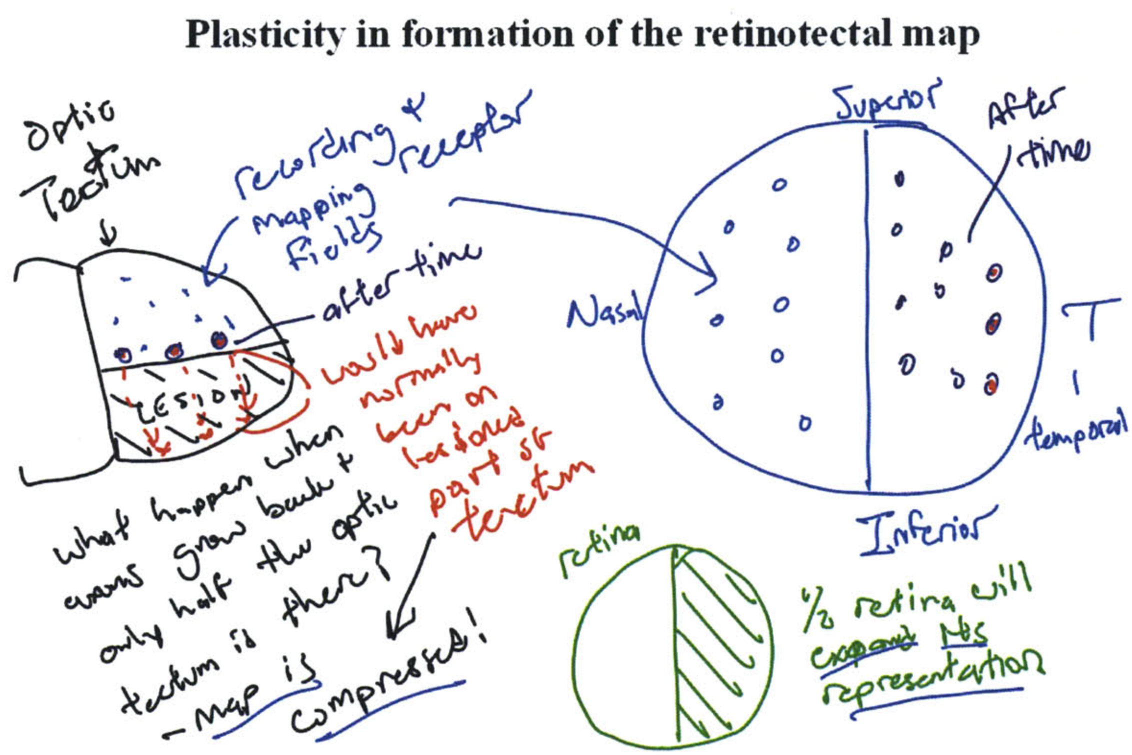


Figure B-47: Example Student Notes—A student creates a diagram along with the Professor

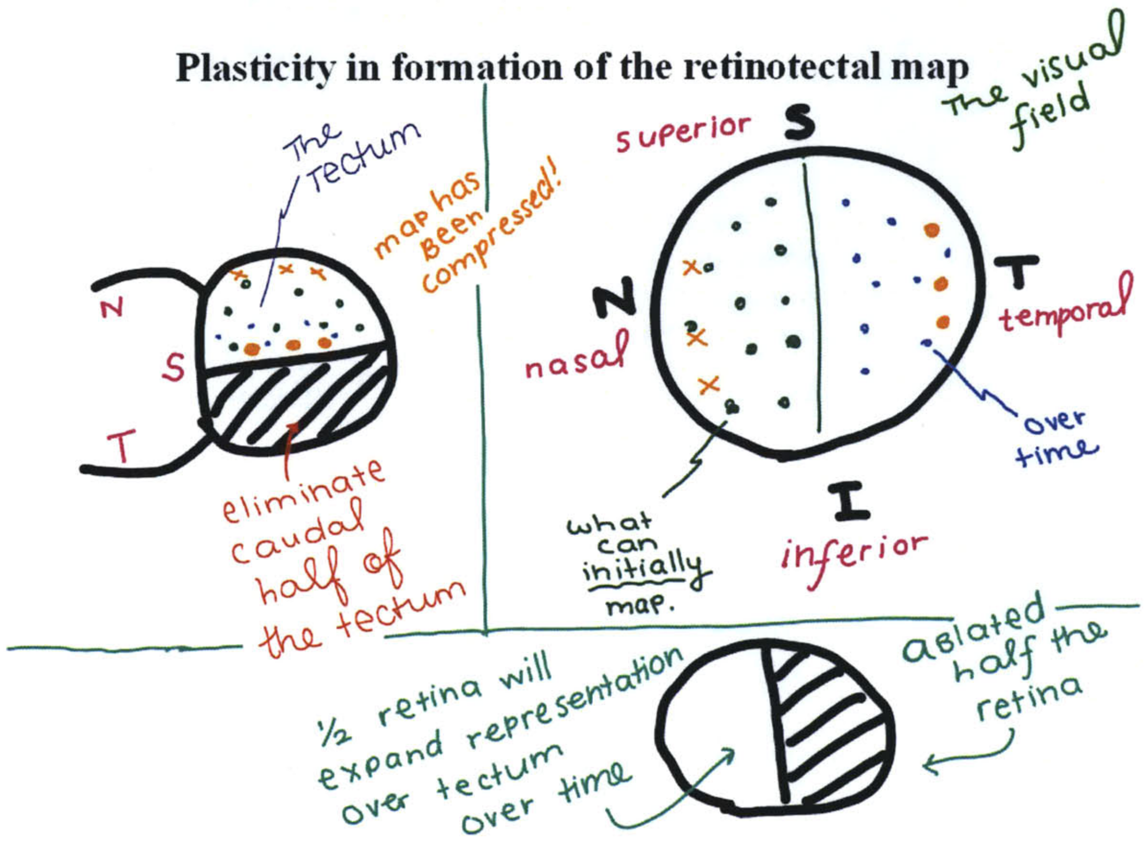


Figure B-48: Example Student Notes—Another student creates the same diagram along with the Professor

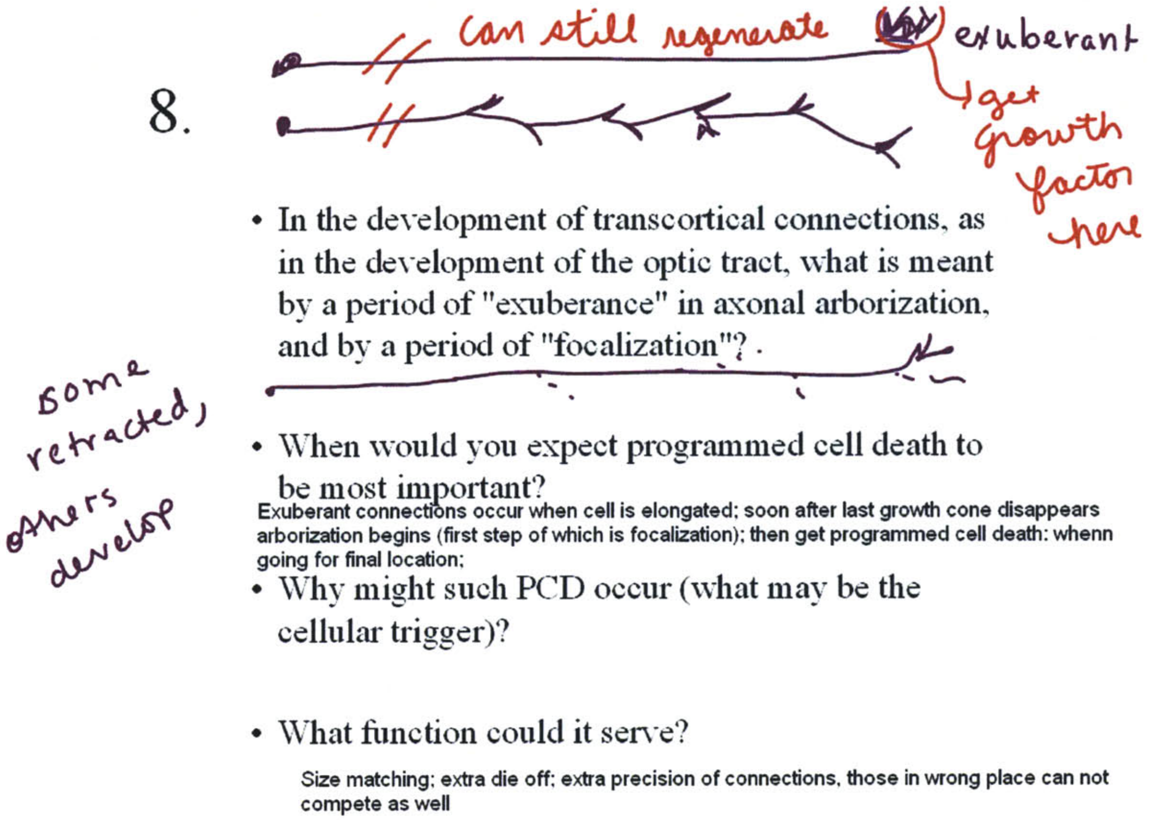


Figure B-49: Example Student Notes—A student makes simultaneous use of the keyboard and stylus during note taking

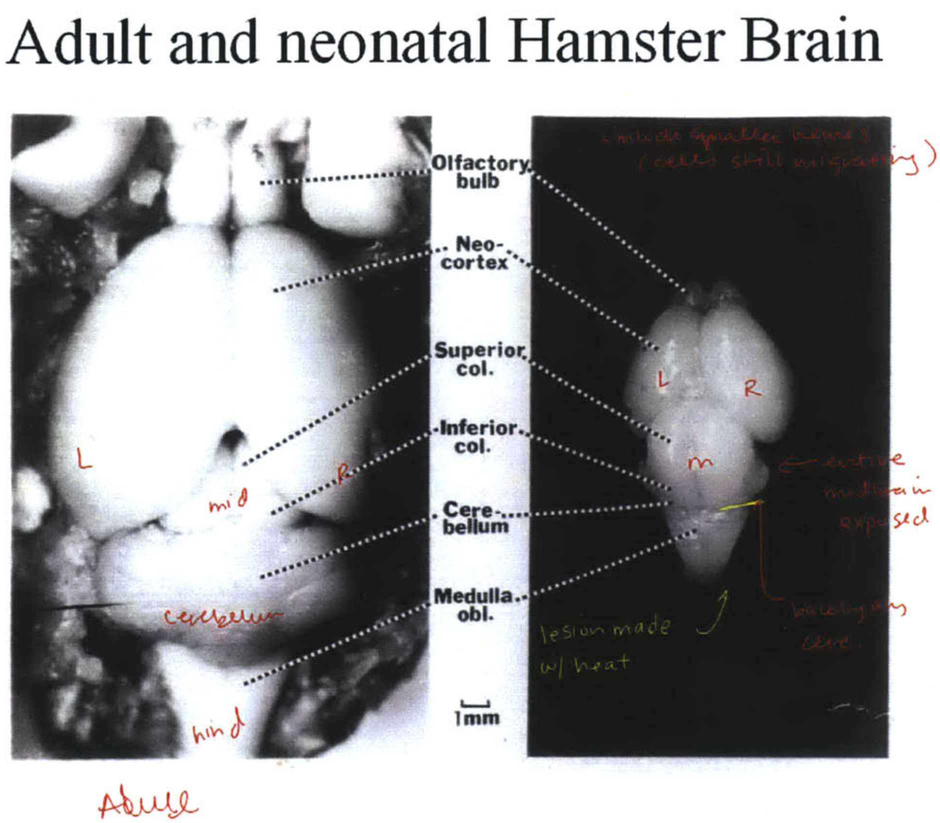


Figure B-50: Example Student Notes—A student writes directly on top of diagrams in a way that would be difficult with paper [46]

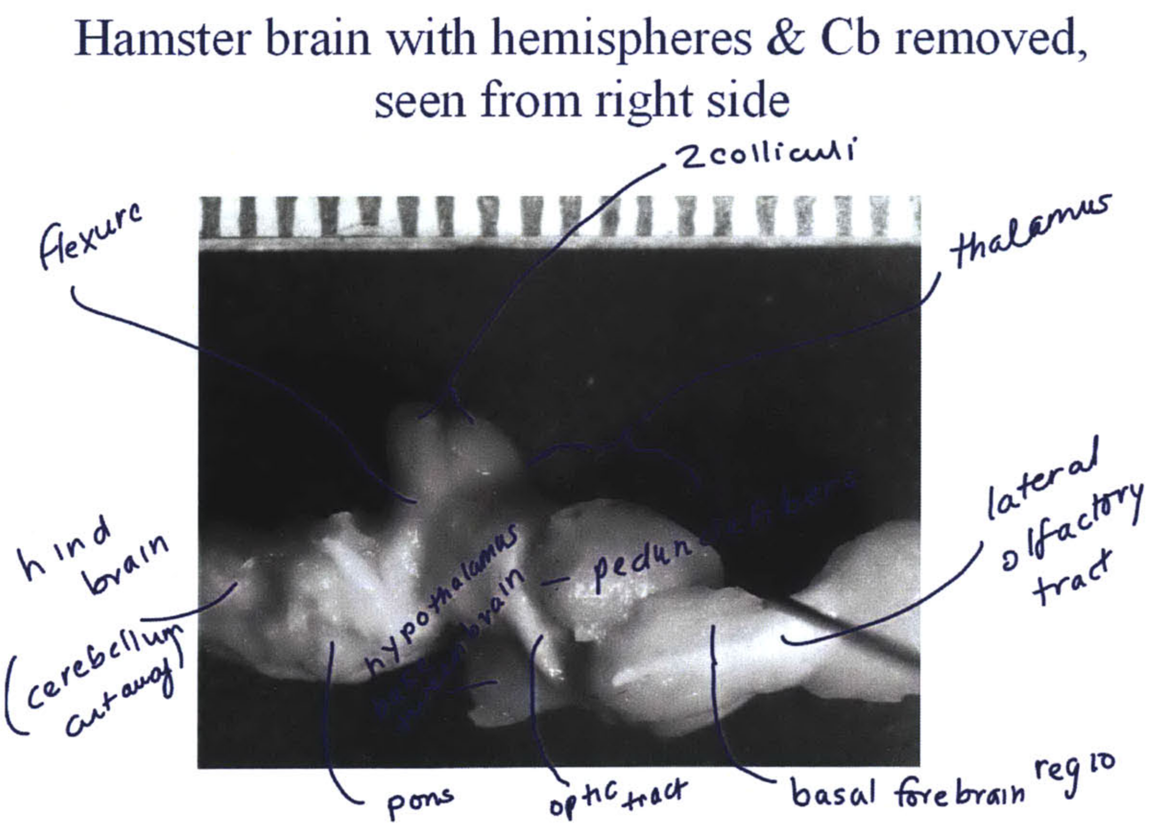


Figure B-51: Example Student Notes—A student writes directly on top of diagrams in a way that would be difficult with paper [46]

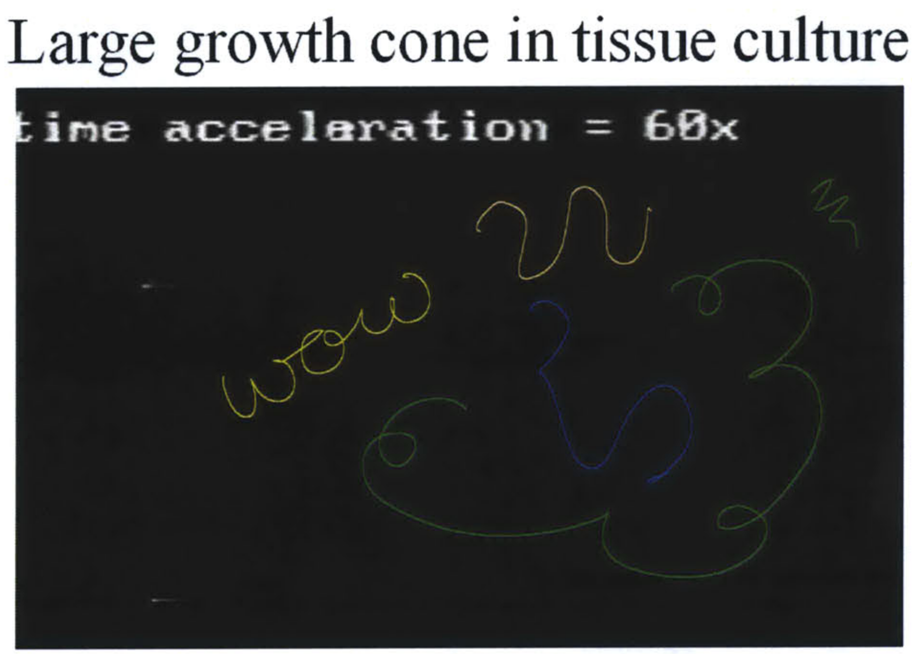


Figure B-52: Example Student Notes—A student writes directly on top of diagrams in a way that would be difficult with paper

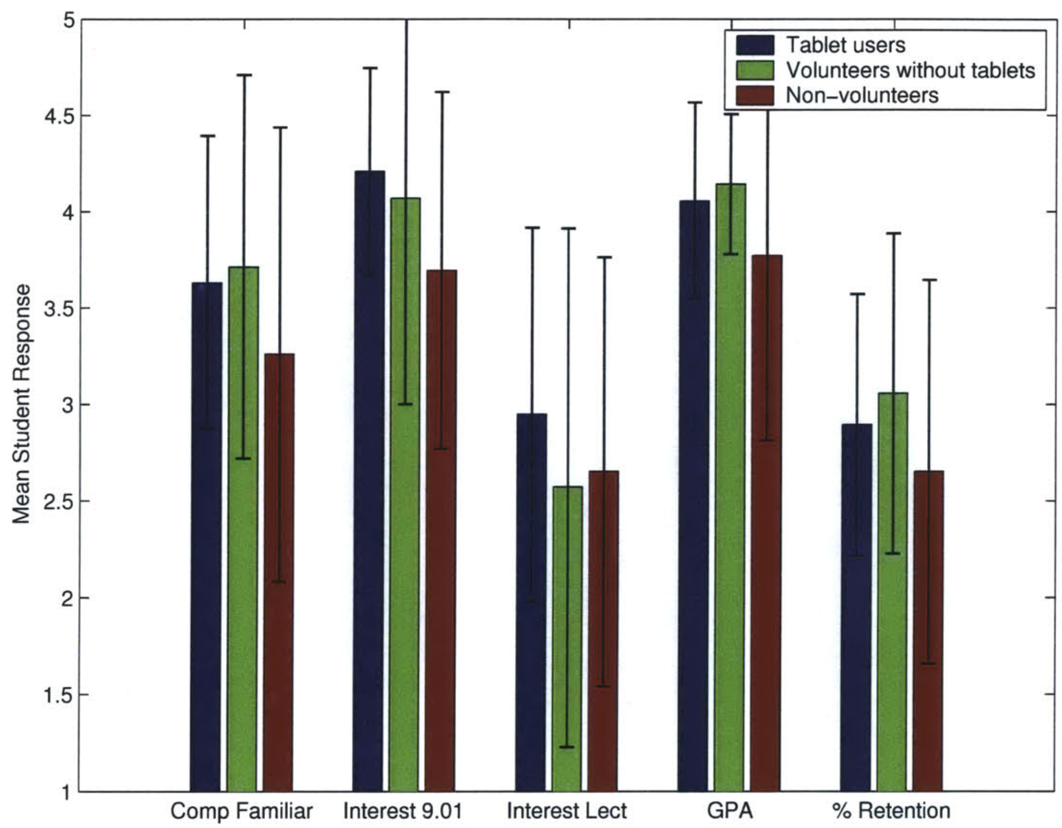


Figure B-53: Retention Surveys—Demographic Questions

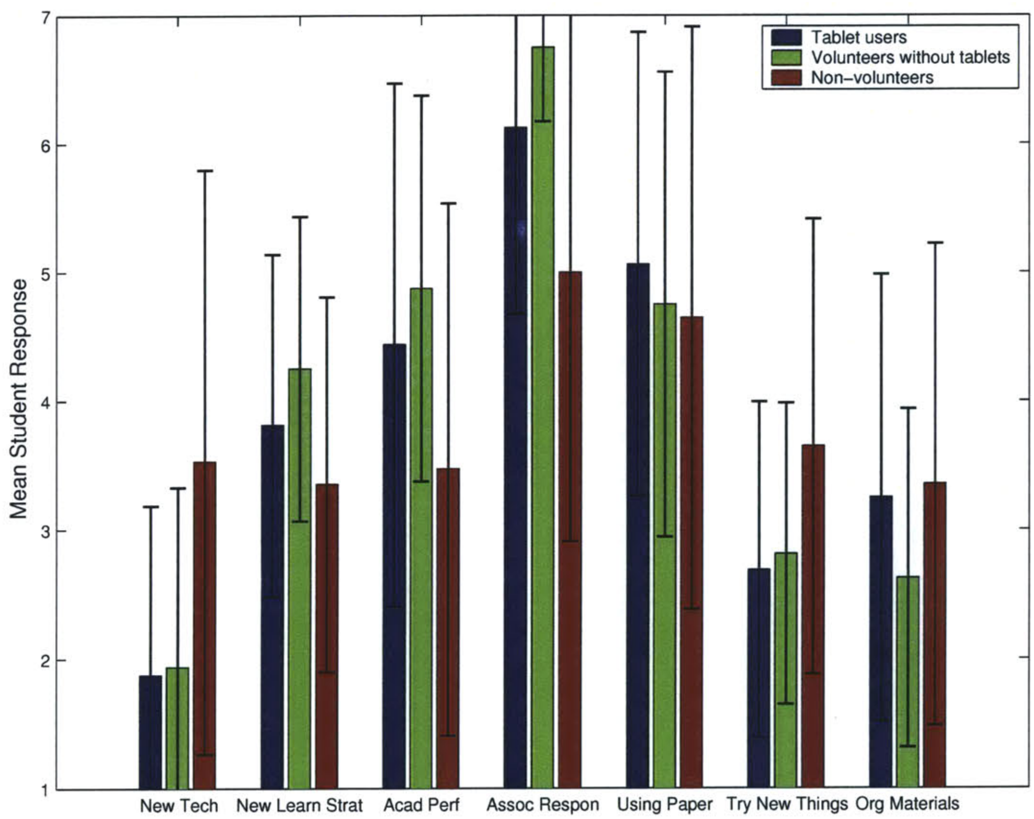


Figure B-54: Retention Surveys—Motivations for Volunteering for a Tablet

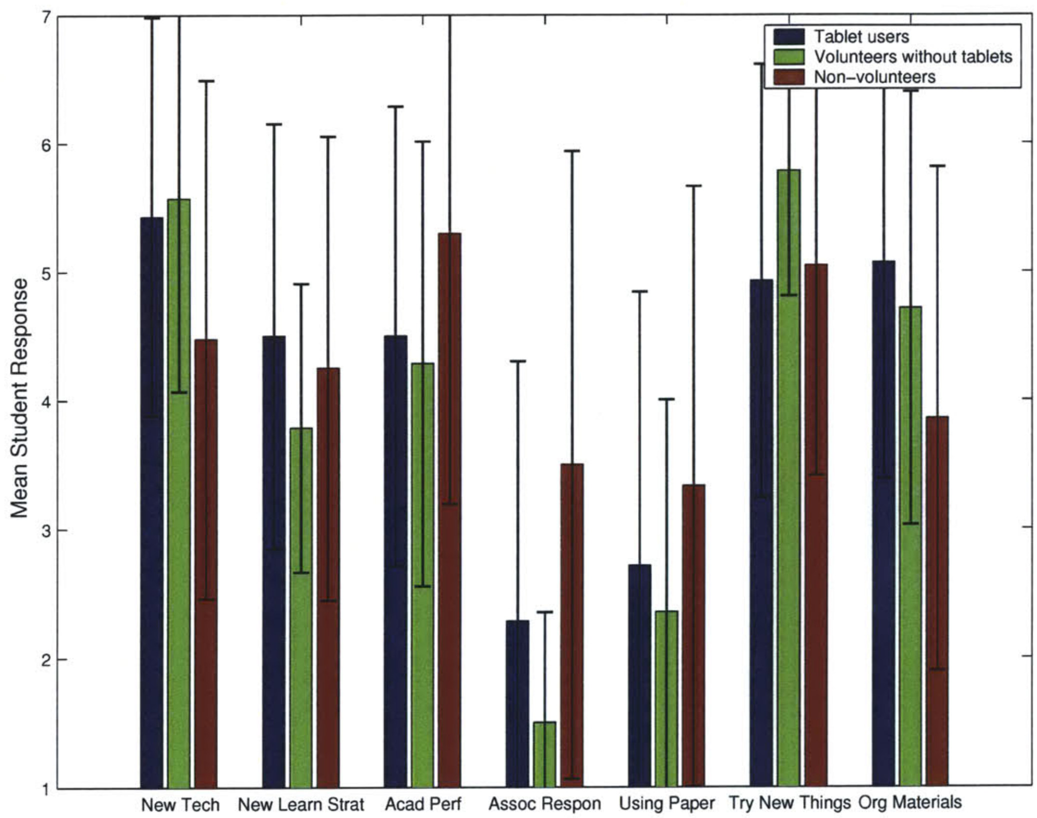


Figure B-55: Retention Surveys—Motivations for Not Volunteering for a Tablet

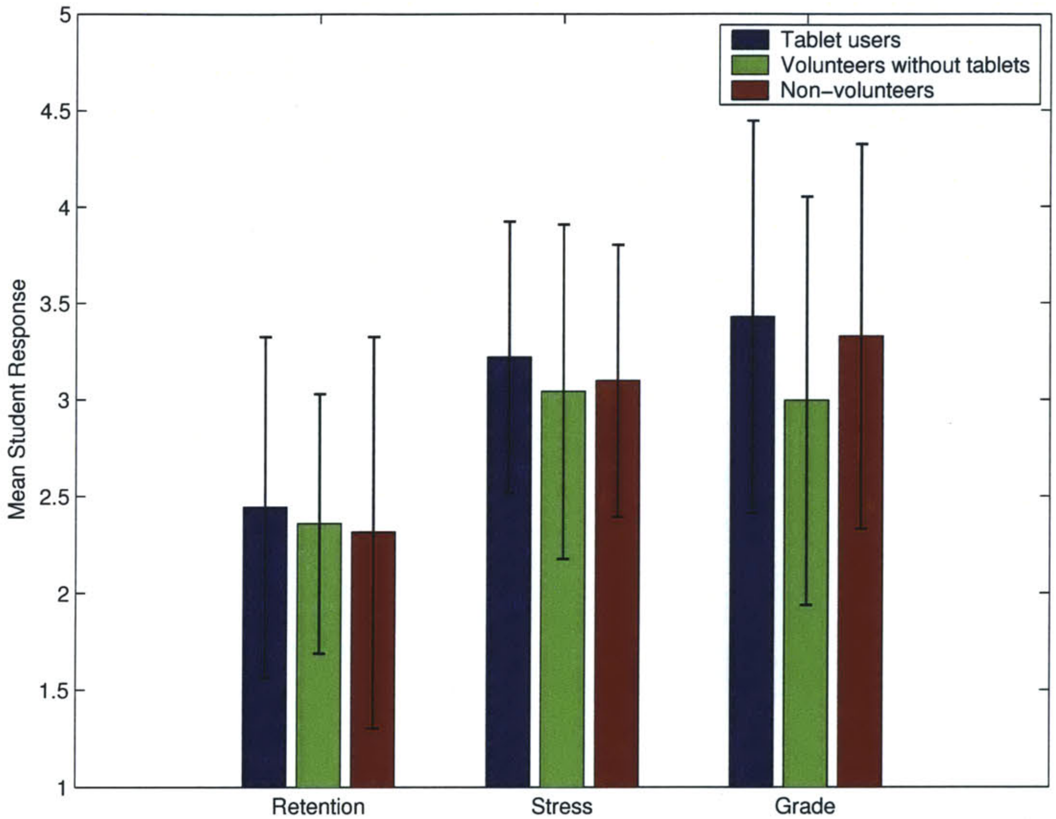


Figure B-56: Retention Surveys—Daily Quiz Questions

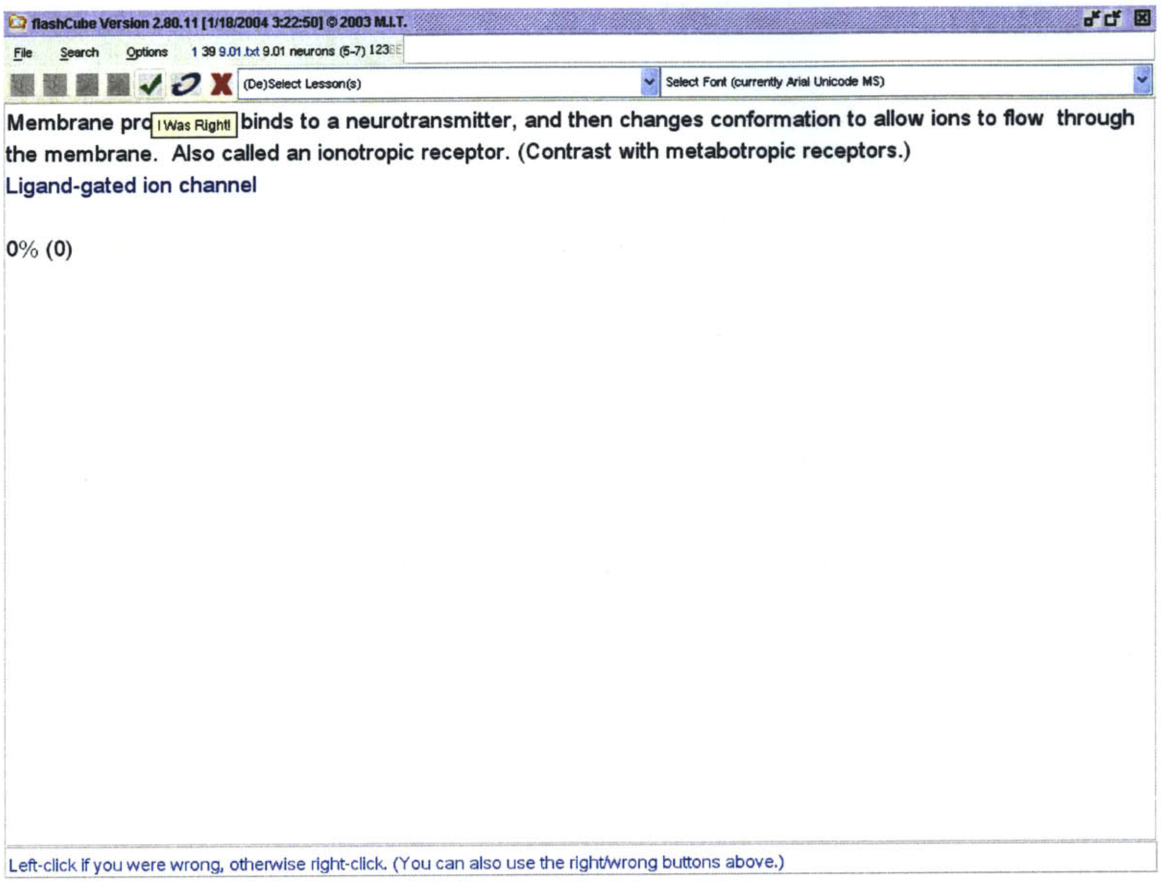


Figure B-57: A Screenshot of the *flashCube* Study Software—Studying Vocabulary

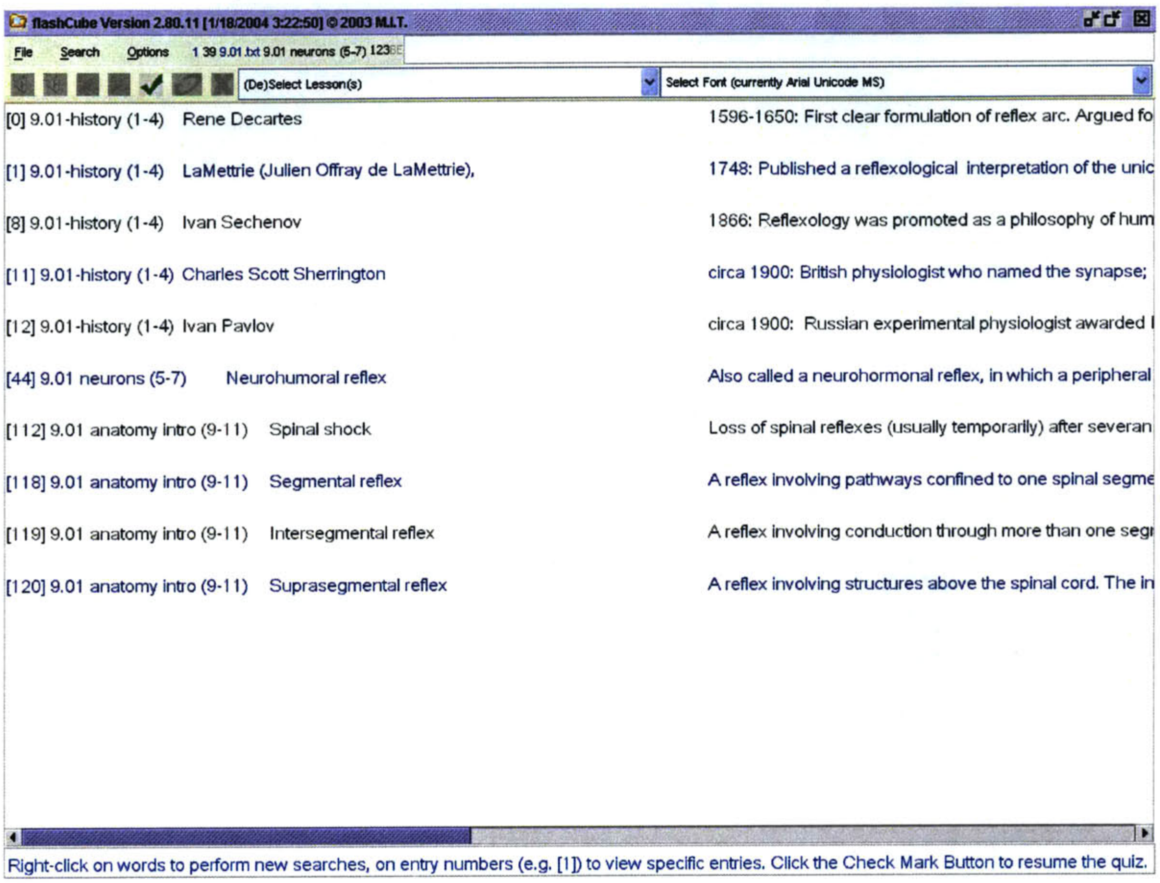


Figure B-58: A Screenshot of the *flashCube* Study Software—Searching the Dictionary

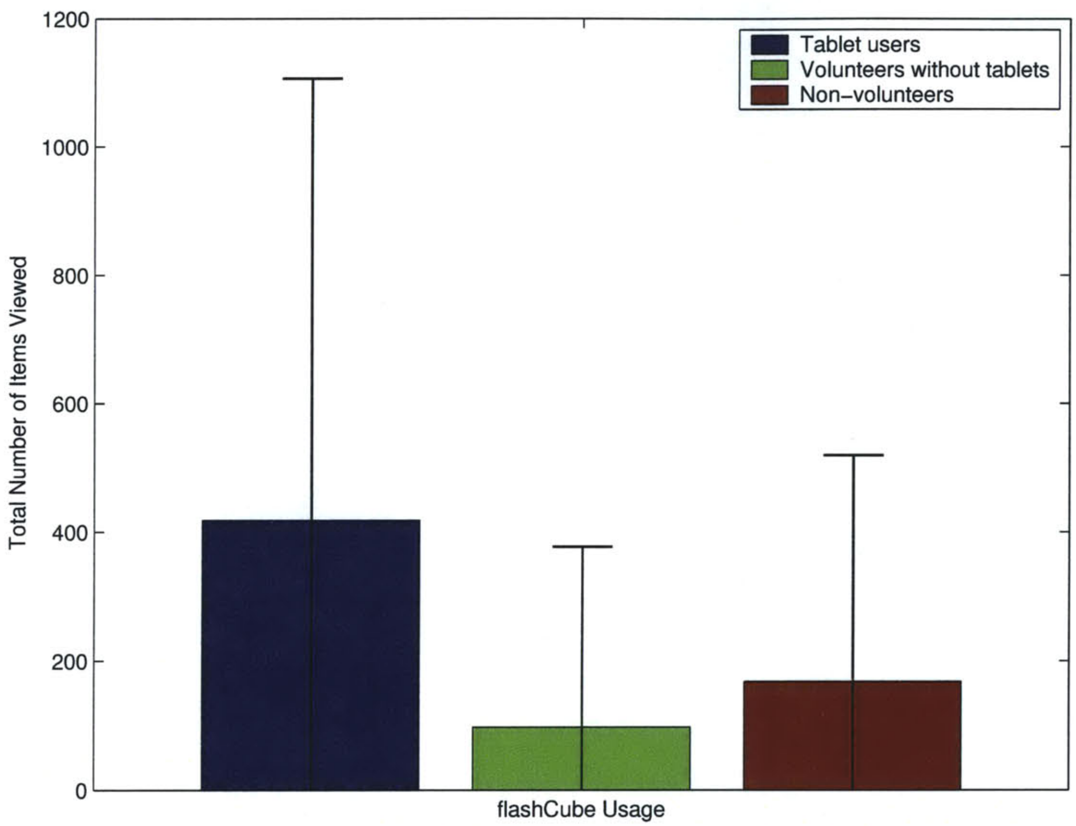


Figure B-59: flashCube Usage Results by Student Category

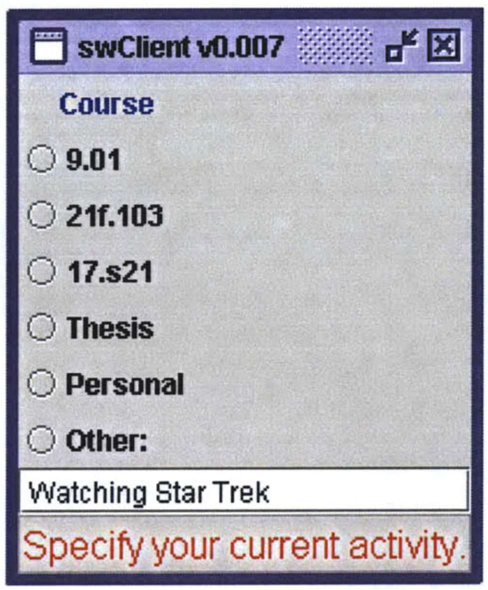


Figure B-60: A Screenshot of the *swClient* Usage Tracking Software

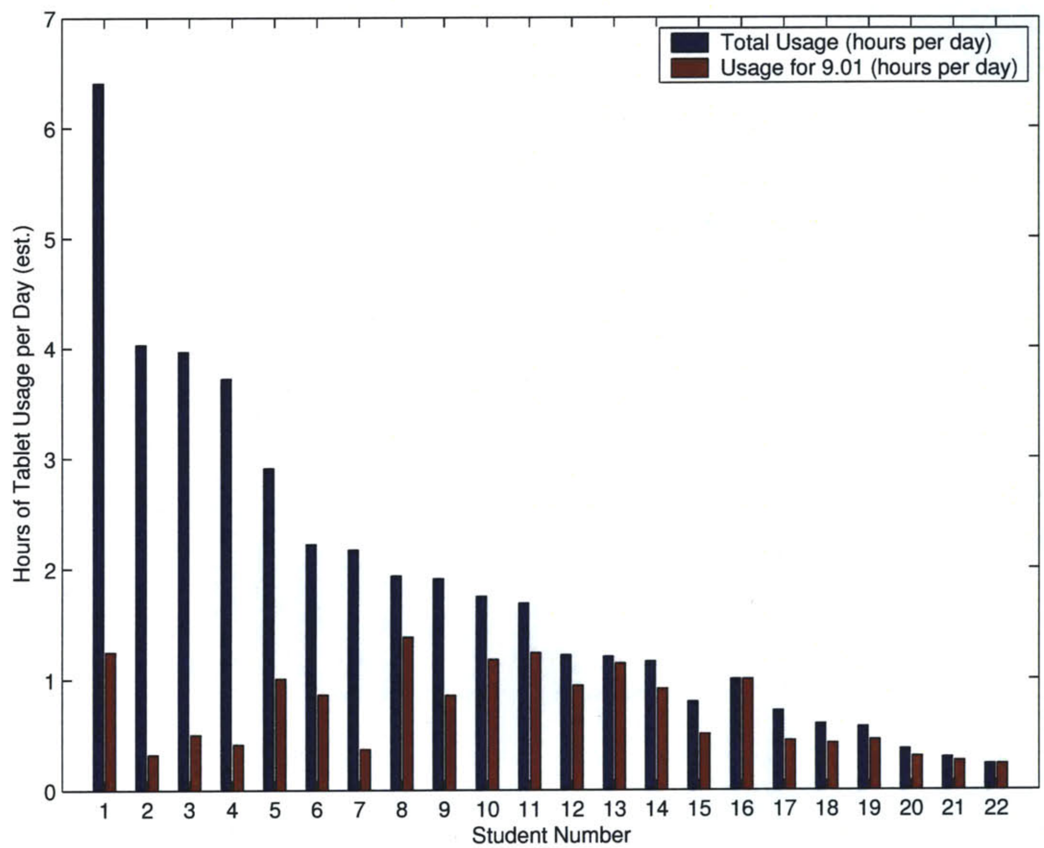


Figure B-61: swClient Average Usage for Each Student, Fall 2003

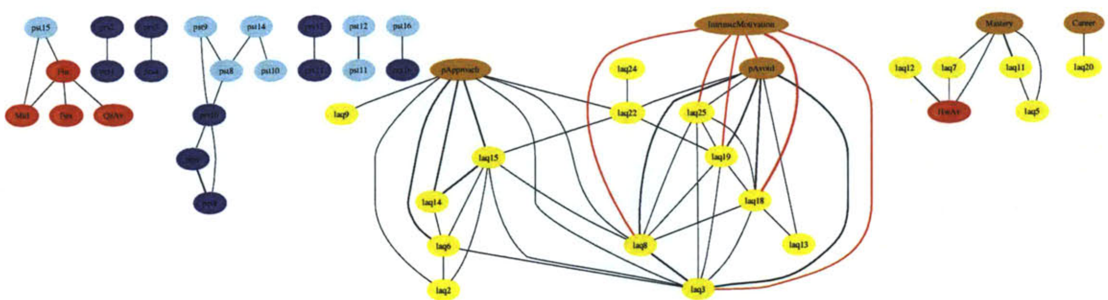


Figure B-62: Correlation Data, 9.14 Spring 2003—$|r| > 0.65, p < 0.001$

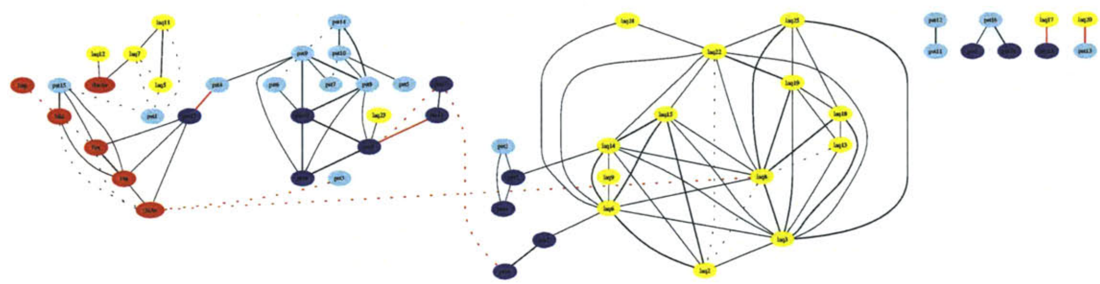


Figure B-63: Correlation Data, 9.14 Spring 2003—$|r| > 0.5, p < 0.01$

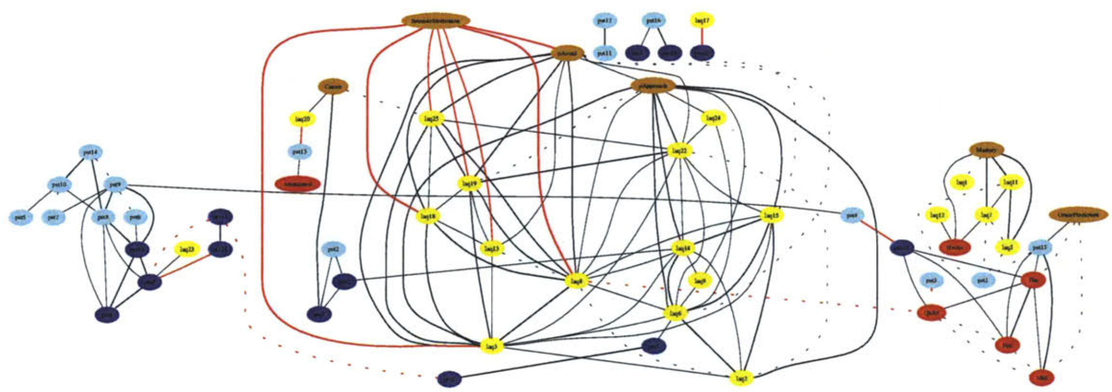


Figure B-64: Correlation Data, 9.14 Spring 2003, with extra LAQ nodes—$|r| > 0.5, p < 0.01$

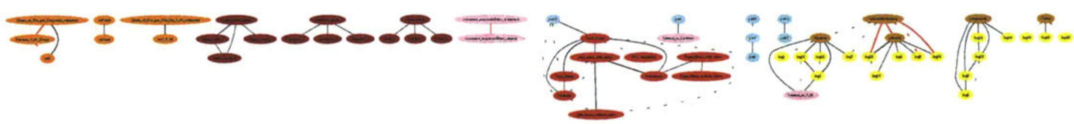


Figure B-65: Correlation Data, 9.01 Fall 2003—$|r| > 0.65, p < 0.001$

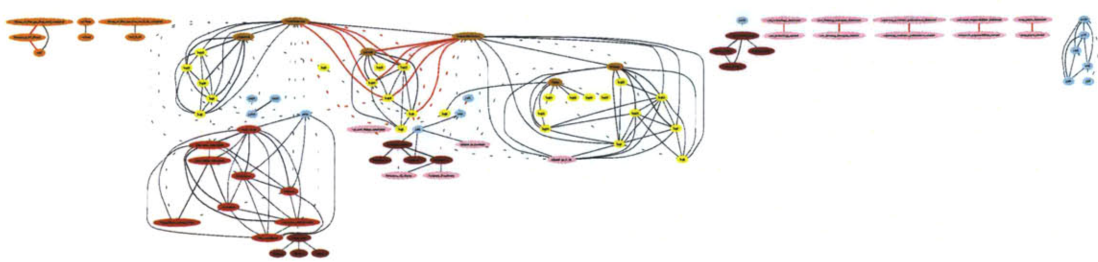


Figure B-66: Correlation Data, 9.01 Fall 2003—$|r| > 0.4, p < 0.001$

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